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METHODS FOR ESTIMATING CARBON DIOXIDE EMISSIONS AND SINKS FROM FOREST MANAGEMENT AND LAND-USE CHANGE

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DISCLAIMER

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INTRODUCTION

The purposes of the preferred methods guidelines are to describe emissions estimation techniques for greenhouse gas sources in a clear and unambiguous manner and to provide concise steps to aid in the preparation of emission inventories. This chapter describes the procedures and recommended approaches for estimating carbon dioxide emissions and sinks from forest management and land-use change.

Section 2 of this chapter contains a general description of the forest management and land-use change source category. Section 3 provides an overview of the available preferred estimation methods to estimate carbon dioxide emissions. Section 4 presents a listing of the steps involved in using either one of the preferred estimation methods; Section 5 is a placeholder section for alternative emission estimation techniques that may be added in the future. Quality assurance and quality control procedures are described in Section 6. References used in developing this chapter are identified in Section 7.

The Intergovernmental Panel on Climate Change (IPCC) is currently re-evaluating the methodology for estimating CO_2 emissions and sinks from forest management and land-use change. The key issue is what lands would be within the scope of an analysis of forest carbon. At one extreme, all accumulation of carbon as forests age would be counted (this approach has been used in developing all national and state inventories in the U.S. to date). At the other extreme, changes in carbon stocks would be counted only for those lands where land use has changed since 1990. Under the latter approach, outlined in Article 3.3 of the Kyoto Protocol and clarified at the Fourth Conference of the Parties in Buenos Aires in November 1998, countries would measure only changes in carbon stocks that resulted from direct human-induced activities of afforestation, reforestation, and deforestation since January 1, 1990. The IPCC is preparing a report to evaluate the implications of different interpretations of this language; the report should be completed by early 2000. Depending on the ultimate interpretation of the language, the IPCC may revise its guidelines for compiling greenhouse gas inventories for forest management and land-use change. Regardless of how the language is interpreted, the methods used to evaluate carbon stocks and flows would be very similar; the only difference would be the relevant land areas for which changes in carbon stocks would be measured. As of the publication date of this document, both of the methodologies presented here (the stock approach and the flow approach) are consistent with the current IPCC methodology.

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SOURCE CATEGORY DESCRIPTION

The biosphere emits and absorbs a wide variety of carbon and nitrogen trace gases, including carbon dioxide (CO_2), methane (CH_4), carbon monoxide (CO), nitrous oxide (N_2O), oxides of nitrogen (NO_x), and nonmethane volatile organic compounds (NMVOCs). When humans use and alter the biosphere through forest management and land-use change activities, such as clearing an area of forest to create cropland, restocking a logged forest, draining a wetland, or allowing a pasture to revert to grassland, the balance between the emission and uptake of these greenhouse gases changes, affecting their atmospheric concentration. In the U.S., forest management is believed to be the primary activity responsible for current greenhouse gas fluxes from land use, and CO_2 is the gas most significantly affected.

This source category accounts for only some of the many agricultural and forestry activities that emit greenhouse gases. Table 10.2-1 summarizes the agricultural and forestry activities associated with emissions of CO_2, CH_4, and N_2O, and provides a roadmap indicating the chapter in which each activity is addressed.

Forests are complex ecosystems with several interrelated components, each of which acts as a carbon storage pool, including:

- trees (*i.e.,* living trees—including roots and foliage, and standing dead trees);
- understory vegetation (*i.e.,* shrubs and bushes);
- the forest floor (*e.g.,* fallen trees, branches, and leaves); and
- soil.

As a result of biological processes (*e.g.,* growth and mortality) and anthropogenic activities (*e.g.,* harvesting, thinning, and other removals), carbon is continuously cycled through these ecosystem components, as well as between the forest ecosystem and the atmosphere. For example, the growth of trees results in the uptake of carbon from the atmosphere and storage in living trees. As these trees age, they continue to accumulate carbon until they reach maturity, at which point they are relatively constant carbon stores. As trees die or drop branches and leaves on the forest floor, decay processes will release carbon to the atmosphere and also increase soil carbon. The net change in forest carbon is the change in the amount of carbon stored in each of these pools (*i.e.,* in each ecosystem component) over time.

The net change in forest carbon, however, is not likely to be equivalent to the net flux between forests and the atmosphere. Because most of the timber that is harvested and removed from U.S. forests is used in wood products, harvests may not always result in an immediate flux of carbon to the atmosphere. Harvesting in effect transfers carbon from one of the “forest pools” to a “product

Table 10.2-1. GHG Emissions from the Agricultural and Forest Sectors

A check indicates emissions may be significant.

Activity	Associated GHG Emissions and Chapter where these Emissions are Addressed					
	CO_2	Chapter	CH_4	Chapter	N_2O	Chapter
Energy (Farm Equipment)	✔	1	✔	13	✔	13
Animal Production: Enteric Fermentation			✔	6		
Animal Production: Manure Management						
Solid Storage			✔	7	✔	7
Drylot			✔	7	✔	7
Deep Pit Stacks			✔	7	✔	7
Litter			✔	7	✔	7
Liquids/Slurry			✔	7	✔	7
Anaerobic Lagoon			✔	7	✔	7
Pit Storage			✔	7	✔	7
Periodic land application of solids from above management practices					✔	Not included [a]
Pasture/Range (deposited on soil)			✔	7	✔	9
Paddock (deposited on soil)			✔	7	✔	9
Daily Spread (applied to soil)			✔	7	✔	9
Animal Production: Nitrogen Excretion (indirect emissions)					✔	9
Cropping Practices						
Rice Cultivation			✔	8		
Commercial Synthetic Fertilizer Application					✔	9
Commercial Organic Fertilizer Application					✔	9
Incorporation of Crop Residues into the Soil					✔	9
Production of Nitrogen-fixing Crops					✔	9
Liming of Soils	✔	9				
Cultivation of High Organic Content Soils (histosols)	✔	Not included [a]			✔	9
Cultivation of Mineral Soils	✔	Not included [a]				
Changes in Agricultural Management Practices (*e.g.*, tillage, erosion control)	✔	Not included [a]				
Forest and Land Use Change						
Forest and Grassland Conversion	✔	10				
Abandonment of Managed Lands	✔	10				
Changes in Forests and Woody Biomass Stocks	✔	10				
Agricultural Residue Burning			✔	11	✔	11

[a] Emissions may be significant, but methods for estimating GHG emissions from these sources are not included in the EIIP chapters.

pool." Once in a product pool, the carbon is emitted over time as CO_2 through either combustion or decay,[1] although the exact rate of emission varies considerably between different product pools and may in fact result in effective long-term carbon storage. For example, if timber is harvested and subsequently used as lumber in a house, it may be many decades or even centuries before the lumber is allowed to decay and carbon is released to the atmosphere. If timber is harvested for energy use, subsequent combustion results in an immediate release of carbon. Paper production may result in emissions over years or decades.

The U.S. land area is roughly 2,263 million acres, of which 33 percent, or 737 million acres, is forest land (Powell *et al.,* 1993). The amount of forest land has remained fairly constant over recent decades—declining by approximately 5 million acres between 1977 and 1987 (USFS, 1990; Waddell *et al.,* 1989) and increasing by about 0.5 million acres between 1987 and 1992 (Powell *et al.,* 1993). These changes represent fluctuations of well under 1 percent of the forest land area, or on average, about 0.1 percent per year. Other major land uses in the U.S. include range and pasture lands (29 percent), cropland (17 percent), urban uses (3 percent), and other lands (18 percent) (Daugherty, 1995).[2] Urban lands are the fastest growing land use.

Given that U.S. forest land area changed by only about 0.1 percent per year between 1977 and 1992, the major influences on the net carbon flux from forest land are management activities and ongoing impacts of previous land-use changes. These activities affect the net flux of carbon by altering the amount of carbon stored in the biomass[3] and soils of forest ecosystems. For example, intensified management of forests can increase both the rate of growth and the eventual biomass density of the forest, thereby increasing the uptake of carbon. The reversion of cropland to forest land through natural regeneration will, over decades, result in increased carbon storage in biomass and soils (*i.e.,* in general, forests contain more biomass and soil carbon than cropland).

In 1996, changes in U.S. forest stocks (including trees, understory, forest floor, and soil), wood product pools, and landfilled wood were estimated to account for net annual sequestration of 230 million short tons of carbon equivalent, corresponding to 209 million metric tons carbon equivalent or 843 million tons of CO_2. This carbon uptake represents an offset of about 14 percent of the CO_2 emissions from fossil fuel combustion (U.S. EPA, 1998).

[1] Actually, if timber undergoes combustion, some small portion of the carbon–as much as 10 percent of the total carbon released–will be released as CO and CH_4 rather than CO_2. In addition, if timber products are placed in landfills, about 50 percent of the carbon that eventually decomposes is oxidized to CO_2 and about 50 percent is released as CH_4. Eventually, both CO and CH_4 oxidize to CO_2 in the atmosphere.

[2] Other lands include farmsteads, transportation uses, marshes, swamps, deserts, tundra, and miscellaneous other lands.

[3] Biomass is a term for organic material. The amount of biomass in a given land area includes all the living and dead organic material, both above and below the ground surface.

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OVERVIEW OF AVAILABLE METHODS

This chapter presents two methods for estimating net annual CO_2 emissions and uptake resulting from forest management and land-use change activities: the "stock approach" and the "flow approach." These approaches are defined as follows:

> Methods for developing greenhouse gas inventories are continuously evolving and improving. The methods presented in this volume represent the work of the EIIP Greenhouse Gas Committee in 1998 and early 1999. This volume takes into account the guidance and information available at the time on inventory methods, specifically, U.S. EPA's *State Workbook: Methodologies for Estimating Greenhouse Gas Emissions* (U.S.EPA 1998a), volumes 1-3 of the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 1997), and the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 1996* (U.S. EPA 1998b).
>
> There have been several recent developments in inventory methodologies, including:
>
> - Publication of EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 1997* (U.S. EPA 1999) and completion of the draft inventory for 1990 – 1998. These documents will include methodological improvements for several sources and present the U.S. methodologies in a more transparent manner than in previous inventories;
> - Initiation of several new programs with industry, which provide new data and information that can be applied to current methods or applied to more accurate and reliable methods (so called "higher tier methods" by IPCC); and
> - The IPCC Greenhouse Gas Inventory Program's upcoming report on Good Practice in Inventory Management, which develops good practice guidance for the implementation of the 1996 IPCC Guidelines. The report will be published by the IPCC in May 2000.
>
> Note that the EIIP Greenhouse Gas Committee has not incorporated these developments into this version of the volume. Given the rapid pace of change in the area of greenhouse gas inventory methodologies, users of this document are encouraged to seek the most up-to-date information from EPA and the IPCC when developing inventories. EPA intends to provide periodic updates to the EIIP chapters to reflect important methodological developments. To determine whether an updated version of this chapter is available, please check the EIIP site at http://www.epa.gov/ttn/chief/eiip/techrep.htm#green.

- Under the stock approach, total forest carbon stocks are measured at two points in time. A net decrease in forest carbon stocks represents net CO_2 emissions. A net increase in forest carbon stocks represents net CO_2 uptake (*i.e.*, carbon sequestration). To calculate the average annual net CO_2 emissions or uptake, the difference between the two carbon stock measurements is divided by the number of years between stock measurements.[4] This is the approach currently used to compile estimates of CO_2 emissions from land-use change and forestry for the annual *Inventory of U.S. Greenhouse Gas Emissions and Sinks*

[4] Because this approach produces an *average* value for carbon sequestration during the period between the two carbon stock measurements, it will not reflect any change in the rate of sequestration during that period.

prepared by the U.S. Environmental Protection Agency (U.S. EPA 1999). The foundation of the stock approach presented in this chapter is consistent with the *IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/UNEP/OECD/IEA, 1995), and the *Revised 1996 IPCC Guidelines for National Greenhouse Inventories* (IPCC/UNEP/OECD/IEA, 1997).

- Under the flow approach, annual changes in forest carbon stocks are calculated by estimating carbon fluxes from annual biomass growth and biomass removals, and the associated changes in soils. The carbon fluxes are calculated separately for three types of land-use activities: (1) changes in forest and other woody biomass stocks; (2) forest and grassland conversion; and (3) abandonment of managed lands. The flow approach outlined in this chapter is consistent with the *IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/UNEP/OECD/IEA, 1995).[5]

In this analysis, either the stock approach or the flow approach may be used to estimate CO_2 fluxes from the following forest management and land-use change activities:

- changes in the amount of biomass in existing biomass stocks on forests and other land, without changes in the way land is used (*e.g.,* management of standing forests, urban tree planting, logging), or

- changes in the way land is used (*e.g.,* clearing forests for agricultural use or suburban development, converting a grassland to cropland).

It is important to note that neither method addresses fluxes of non-CO_2 greenhouse gases (*i.e.,* CH_4, CO, N_2O, NO_x, and NMVOCs) that may also be associated with these activities. Emissions of non-CO_2 gases that result from biomass burning (*i.e.,* wood consumption for energy production) are captured in Chapter 14. Emissions of these gases due to other activities, such as land flooding and wetland drainage, are discussed as areas for further research in the uncertainties section of this chapter.

Both the stock approach and the flow approach operate under the assumption that the net flux of CO_2 to or from the atmosphere as a result of forest management and land-use change activities is equal to the net change in the carbon stocks of biomass (trees, understory, and litter) and soil. The stock and flow approaches use different processes to calculate the net change in carbon stocks of biomass and soil, and each approach requires different kinds of activity data.

Under both the stock and flow approaches, all of the carbon contained in removed biomass is assumed to be emitted to the atmosphere at the time of removal. In actuality, some portion of this carbon may be stored in durable wood products or landfills. Although the long-term storage of carbon in wood products and landfilled wood is accounted for in the *Inventory of U.S. Greenhouse*

[5] Note that this flow approach does not reflect changes to the IPCC methodology presented in the *Revised 1996 IPCC Guidelines for National Greenhouse Inventories*, which were published in 1997 (IPCC/UNEP/OECD/IEA, 1997). The most significant change in the new methodology relates to the estimation of carbon fluxes from forest and non-forest soils. The latest IPCC methodology has not been incorporated into this chapter because many of the data required to apply this approach are not readily available in the U.S.

Gas Emissions and Sinks: 1990-1997 (U.S. EPA 1999), this kind of carbon storage cannot be easily estimated on a state-by-state basis because the processes of harvesting wood, manufacturing wood products, and disposing of wood and wood products often cross state lines. In addition, this measurement process is complicated by the fact that new products from current timber harvests frequently replace existing product stocks, which are in turn discarded and oxidized. Assuming that all carbon in removed biomass is released to the atmosphere at the time of removal is considered a legitimate, conservative assumption for initial calculations.

Both stock and flow approaches are presented in this chapter to accommodate users with different levels of available data, *i.e.*, data with different levels of complexity and at different geographic scales. States are encouraged to apply either method in as detailed a manner as their data allow, as well as to estimate emissions from land-use activities that are not explicitly included in these methods if expertise and data are sufficient.[6]

Ideally, the stock and flow approaches should enable a state to use different types of activity data--either biomass and soil carbon stock data (stock approach), or data on tree growth, mortality, and harvests, soil carbon fluxes, and land-use changes (flow approach)--to produce the same estimate of net CO_2 fluxes from forestry and land-use change activities. However, the stock and flow approaches outlined in this report may in fact produce quite different CO_2 flux estimates for several reasons, including the following:

- States may not be able to produce activity data sets for each approach that are of equal quality and comprehensiveness.

- The USFS default data used in the stock approach are specific to U.S. forest types and are disaggregated by forest type and/or region to a greater extent than the IPCC default data used in the flow approach.

- The IPCC default data on biomass stocks (used in the flow approach) account for only aboveground biomass, whereas the USFS default conversion ratios (used in the stock approach) account for both aboveground and belowground biomass.

- The IPCC flow approach tracks carbon fluxes from forest and grassland conversion and abandonment of managed lands. The stock approach outlined in this report is dependent upon forest data provided by USFS, and these data do not include trees and other biomass on lands that are not classified as forests.

- The IPCC flow approach excludes carbon fluxes from natural and undisturbed forests, where they still exist and are in equilibrium. It is not clear whether the IPCC definition of a “natural and undisturbed forest” can be applied to any of the forests in the United States. The USFS forest inventories do not classify forests as “disturbed” or “undisturbed.”

[6] Note that the University of Edinburgh’s Institute of Ecology and Resource Management, with funding from the UK DFID’s Forestry Research Programme, has developed a provisional set of guidelines and criteria for assessing carbon offsets projects. Further information on this approach for estimating net CO_2 emissions from carbon offsets projects please refer to the following website, www.ed.ac.uk/~ebfr11/ecor.

- The stock and flow approaches rely on different time series of data. Under the stock approach, one measures the carbon stocks at two points in time and calculates an average annual change in carbon stocks. In states with infrequent forest inventories, the estimate of annual carbon flux based on two points separated by a long interval may not accurately reflect recent trends. Under the flow approach, one estimates the carbon flux from changes in forest and other woody biomass stocks, and soil carbon flux, in a single inventory year. The carbon flux from biomass growth is calculated by applying an average annual growth rate per unit of forest area, and the carbon flux from biomass removal is calculated based on the actual volume of harvested timber and fuelwood in the inventory year. The extent to which this part of the flow approach more accurately reflects recent trends depends on how the average annual biomass growth rate is calculated. Neither of the methodologies used to calculate the annual biomass growth rate (*i.e.*, the IPCC method for default values, and the U.S. Forest Service method for state-specific values) is well documented; thus, the reliability of these calculations is not known. Therefore, when using the stock and flow approaches, there may be a tradeoff between using direct carbon stock measurements that are collected infrequently (under the stock approach), and applying estimates of average annual biomass growth and decay developed using methodologies that are not well documented (under the flow approach).

These discrepancies between the stock and flow approaches generally are the result of (1) the underlying complexity of forest ecosystems, and (2) a lack of comprehensive data on carbon stocks and carbon fluxes for all ecosystem components and land uses. States are advised to select the approach that makes the most effective use of their activity data on forestry and land-use change activities.

Despite these discrepancies, both the stock and flow approaches outlined in this report will enable states to develop a baseline inventory of carbon fluxes from forestry and land-use change activities, and to develop *consistent* inventories of these fluxes in subsequent years. The baseline inventory will provide states with important information that can be used to identify and prioritize strategies for reducing carbon emissions and/or increasing carbon sequestration from forestry and land-use change activities. The development of subsequent inventories using a consistent methodology will enable states to measure the success of their efforts.

4

PREFERRED METHODS FOR ESTIMATING EMISSIONS

4.1 STOCK APPROACH

The stock approach consists of the measurement of total biomass and soil carbon stocks at two points in time. A net decrease in these stocks is equated with net CO_2 emissions, whereas a net increase in these stocks is equated with net CO_2 uptake (*i.e.*, carbon sequestration). As discussed in the previous section, for the purpose of compiling a state greenhouse gas inventory, it is assumed that all of the carbon contained in removed biomass is emitted to the atmosphere at the time of removal. To calculate the average annual net CO_2 emissions or sequestration from forest management and land-use change activities, the difference between the two carbon stock measurements is divided by the number of years between stock measurements, and the annual carbon flux is reported on a full-molecular-weight basis in units of short tons of CO_2 emissions or sequestration.

In order to measure the changes in total biomass and soil carbon stocks, these stocks are subdivided into four ecosystem components: trees, understory, forest floor, and soil. The carbon stocks in each ecosystem component are measured or estimated separately. The change in the carbon stocks of each component represents the apparent carbon flux associated with that component. This flux from each ecosystem component is referred to as an *apparent* flux rather than a *net* flux because this flux may represent a transfer of carbon stocks between ecosystem components as well as between the biosphere and the atmosphere. The net carbon flux between the biosphere and the atmosphere is calculated by summing the apparent flux from each of the ecosystem components.

The methods in this section follow the IPCC sign conventions for expressing CO_2 fluxes. Emissions are assigned a positive value, and sequestration a negative value. However, an increase in carbon stocks is initially assigned a positive value, and a decrease in carbon stocks a negative value. This convention results in the requirement that when converting an estimated change in carbon stocks to net emissions or sequestration, the carbon stock change should be multiplied by a negative one (-1).

The stock approach can be applied using data from the two most recent forest timber inventories conducted for each state by the U.S. Forest Service (USFS). The regional Forest Service Research Stations conduct state forest timber inventories on cycles that vary by state and that average ten years per state (Powell *et al.,* 1993). Depending on the USFS publications or electronic databases used, states may be able to obtain data on the volume or dry weight of merchantable timber, or on the volume or dry weight of all tree biomass. States may be able to obtain breakdowns of these data by tree species, species type, forest type, diameter class, and ownership. The availability of these data may vary from state to state, and from forest inventory to forest inventory. States should carefully select the data set used to generate their greenhouse gas inventory for the forestry and land-use change sector. The data set should include all forest land (*i.e.*, timberland, productive reserved forest land, and other forest land).[7] The data set should enable states ultimately to estimate the total mass of tree biomass on a dry-weight basis by species or forest type. States should confirm that the default conversion factors provided in this chapter for estimating total forest carbon stocks are applicable to the data set selected, or should develop their own conversion factors.

The application of the stock approach at the state level is complicated by a lack of state-specific data on understory, forest floor, and soil carbon stocks. For the purpose of compiling national forest carbon stock estimates, USFS has developed models for estimating understory, forest floor, and soil carbon stocks based on merchantable timber stock data collected in state forest inventories. However, these models are not publicly available at this time. If states cannot develop their own estimates of carbon stored in understory biomass, litter, and forest soils, then they may apply the default data provided in this chapter. However, the application of the default data will increase the level of uncertainty of the final carbon flux estimates. States also must decide whether to include carbon fluxes associated with non-forest trees, such as urban trees, which are not included in USFS forest timber inventories. To the extent that data are available, states are encouraged to develop their own estimates of carbon fluxes from changes in non-forest tree, understory, litter, and soil carbon stocks.

The procedure for calculating the carbon stocks and the apparent carbon flux for each ecosystem component is presented below. Because the precise methodology for applying the stock approach will vary according to the data sources available to each state, worksheets for the stock approach have not been included in this document.

4.1.1 Apparent Carbon Flux from Trees

The apparent carbon flux from trees results from net changes in the volume of standing tree biomass due to tree growth, mortality, and harvests. Using the stock approach, one estimates the net result of all of these processes simply by measuring the total tree biomass stocks at two points in time, estimating their carbon content, and calculating the difference between the two carbon stock estimates. This calculation consists of the following steps:

Step (1) Obtain Required Data

Required Data. The basic data required to calculate the carbon stored in tree biomass consist of: (1) the total mass of tree biomass (including the main stem, branches, leaves, and roots) by species

[7] Forest land in the U.S. includes all land that is at least 10 percent stocked with trees of any size. Land classified as "timberland" is the most productive type of forest land, growing at a rate of 20 cubic feet per acre per year or more. In 1992, there were about 490 million acres of timberlands, which represented 66 percent of all forest lands (Powell et al. 1993). Forest land classified as timberland is unreserved forest land that is producing or is capable of producing crops of industrial wood. The remaining 34 percent of forest land is classified as "productive reserved forest land," which is withdrawn from timber use by statute or regulation, or "other forest land," which includes unreserved and reserved unproductive forest land.

and/or forest type on a dry-weight basis (*i.e.*, in units of short tons of dry matter); and (2) the carbon content of the tree biomass by species and/or forest type on a dry-weight basis. If forest inventory data are not reported in units of mass on a dry-weight basis, then the following data may be used: (1) volume of merchantable timber (by species and/or forest type); (2) expansion ratios for converting the volume of merchantable timber to total tree biomass volume (both above- and belowground); (3) biomass conversion ratios (by species and/or forest type) to convert volume of tree biomass to mass on a dry-weight basis; and (4) the carbon content of the tree biomass (by species and/or forest type) on a dry-weight basis. These data should be obtained for the two most recent forest inventory years.

Data Sources.

Tree Biomass Stocks: Data on tree biomass stocks are compiled via periodic forest inventories conducted on a state-by-state basis by the regional stations of the U.S. Forest Service (USFS). USFS publishes these data in multiple formats, and is currently developing new reporting methods and databases. Therefore, while some states may already be able to obtain tree biomass data on a dry-weight basis (*i.e.,* in units of short tons of dry matter), other states currently may be able to obtain tree biomass data only in units of volume (*i.e.,* cubic feet). In addition, some USFS data sources report tree biomass data only for the merchantable portion of the timber, whereas others report data on total tree biomass. Therefore, it is important to pay close attention to the type of forest inventory data available for each state from USFS, and to select appropriate factors for estimating the total tree biomass volume, specific gravity, and carbon content. It should be noted that USFS forest inventories exclude non-forest trees, such as urban trees. States may therefore need to develop their own data on non-forest tree biomass stocks if they believe that the net carbon fluxes from these stocks are significant.

Expansion Ratios, Biomass Conversion Ratios, and Biomass Carbon Fractions: Expansion ratios represent the ratio of merchantable timber volume to total tree volume; biomass conversion ratios are a measure of the density (mass of dry matter per unit volume); and the carbon fraction is a measure of mass of carbon per total dry matter mass. These factors vary according to tree species, forest type, age class, and climatic region. Birdsey (1992)[8] developed default values for these factors by region and forest type. These default values are presented at the end of this section in Tables 1.1 and 1.2. However, some states may find it difficult to apply these values to their inventory data due to differences in forest classification systems. In addition, it should be noted that the expansion ratios in Table 1.1 from Birdsey (1992) should be applied to data on "the volume of live trees of commercial species at least 5.0 inches in diameter at breast height (d.b.h.) and meeting specified standards of quality." If a state includes trees of less than 5.0 inches d.b.h. in its forest inventory data, then different expansion ratios should be applied. States that are unable to apply the default data from Birdsey (1992) are encouraged to develop their own data from forestry literature and cite the sources of these data in their greenhouse gas inventory.

[8] Birdsey, Richard A. 1992. *Carbon Storage and Accumulation in the United States Forest Ecosystems*. USDA Forest Service. General Technical Report WO-59.

Units for Reporting Data. Data should be reported in the following units:

- Tree biomass volume: cubic feet of merchantable timber or total tree biomass (ft^3)
- Expansion ratios: total tree biomass volume to merchantable timber volume (ft^3/ft^3)
- Biomass conversion ratios: mass in short tons of dry matter per cubic foot (t dm/ft^3)
- Biomass carbon fraction: tons carbon per ton dry matter (t C/t dm)

Step (2) Calculate the Mass of Total Tree Biomass Stocks in Each Forest Inventory Year

If state data are available on the total tree biomass (both above- and belowground) in units of short tons of dry matter, then proceed to Step 3. If not, then perform the following calculation for each of two forest inventory years:

- Obtain state forest inventory data on the volume of merchantable timber of at least 5.0 inches d.b.h. by forest type (as defined by USFS, *e.g.,* pines, oak-hickory, oak-pine, etc.), and by species type (*i.e.,* softwood and hardwood).

- Multiply the volume of merchantable timber by the appropriate expansion ratio (defined by region and by species type) to calculate the total volume of above- and belowground biomass for all live and dead trees. (Refer to Table 1.1 of Birdsey (1992) at the end of this section for default expansion ratios.)

- Multiply the total volume of tree biomass by the biomass conversion ratio to calculate the mass of tree biomass on a dry-weight basis. (Refer to Table 1.2 of Birdsey (1992) at the end of this section for default specific gravities that may be used to calculate the biomass conversion ratio according to region, forest type, and species type.[9] The IPCC default value for the biomass conversion ratio is 0.016 t dm/ft^3.)

- To the extent available, obtain data on the mass of biomass contained in non-forest trees, and add this amount to the total mass of forest tree biomass.

[9] The biomass conversion ratio can be calculated by multiplying the specific gravity of the tree biomass by the weight of a cubic foot of water (62.4 lbs). Please note that the biomass conversion ratios derived from Birdsey (1992) are in units of pounds per cubic foot. To convert the mass to short tons, multiply the mass in pounds by the ratio of 0.0005 short tons per pound.

Step (3) Calculate the Carbon Contained in Tree Biomass in Each Forest Inventory Year

- For each of two forest inventory years, multiply the mass of tree biomass on a dry-weight basis by the biomass carbon fraction to calculate the total tree carbon stocks in each inventory year. (Refer to Table 1.2 of Birdsey (1992) at the end of this section for biomass carbon fractions by region, forest type, and species type. The IPCC default value for the biomass carbon fraction is 0.5.)

Step (4) Calculate the Apparent Average Annual CO_2 Flux from Changes in Tree Stocks between Forest Inventory Years

- Calculate the difference between total tree carbon stocks in the two inventory years. A net decrease in tree carbon stocks represents carbon emissions. A net increase in tree carbon stocks represents carbon sequestration.

- Divide the difference in tree carbon stocks by the number of years between forest inventories to calculate the apparent average annual carbon flux for the period between forest inventories.

- To be consistent with the IPCC sign convention, net carbon emissions (as CO_2) should be expressed as a positive value, and net carbon uptake as a negative value.

4.1.2 Apparent Carbon Flux from Understory

The apparent carbon flux from understory biomass results from net changes in the volume of standing understory biomass due to growth, mortality, and harvests. Using the stock approach, one estimates the net result of all of these processes by measuring the total understory biomass stocks at two points in time, estimating their carbon content, and calculating the difference between the two carbon stock estimates. This calculation consists of the following steps:

Step (1) Obtain Required Data

Required Data. The basic data required to calculate the carbon stored in understory biomass consist of: (1) the total mass of understory biomass (including the main stem, branches, leaves, and roots) by species and/or forest type on a dry-weight basis (*i.e.*, in units of short tons of dry matter); and (2) the carbon content of the understory biomass a dry-weight basis.

Data Sources.

> **Understory Biomass Stocks:** USFS currently does not report data on the volume or mass of understory biomass in its state forest inventories. If possible, states should use their own data on understory biomass stocks expressed on a dry-weight basis.

Understory Biomass Carbon Content: If states are using their own understory biomass stock data, then they will need to obtain data on biomass carbon contents on a dry-weight basis. A default value of 0.45 may be used if state-specific data are not available.

USFS Model for Estimating Understory Biomass Carbon Stocks: USFS has developed a model for estimating the quantity of carbon stored in understory biomass as a function of merchantable timber volume. This model is used to produce the understory carbon stock estimates incorporated into the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1997* (U.S. EPA 1999). However, USFS has not published detailed information on this model. If state data on understory biomass stocks are not available, then states should refer to Table 2.2 of Birdsey (1992), which is included at the end of this section, to obtain state-specific data on average carbon storage in understory biomass per unit of forest area in 1987. In order to apply the data from Birdsey (1992), states need to obtain information on the total forest area in two forest inventory years.

Units for Reporting Data. Data should be reported in the following units:

- Mass of understory biomass: tons of dry matter (t dm)
- Biomass carbon fraction: tons carbon per ton dry matter (t C/t dm)
- Forest area (if using USFS default data): acres
- Average storage of carbon in understory biomass (if using USFS default data): short tons per acre (t C/acre)

Step (2a) Use State Data to Calculate Understory Biomass Carbon Stocks in Each Forest Inventory Year (If using Step (2a), do not use Step 2(b).[10])

- For each forest inventory year, multiply the total understory biomass stocks (in tons of dry matter) by the biomass carbon content. A default biomass carbon content of 0.45 may be used.

Step (2b) Use USFS Data to Calculate Understory Biomass Carbon Stocks (If using Step (2b), do not use Step 2a).

- For each of two forest inventory years, determine the total forest area in the state.

- For each of two forest inventory years, multiply the total forest area by the average understory biomass carbon content. Refer to Table 2.2 from Birdsey (1992) at the end of this section for default values for the year 1987.

[10] Use Step (2b) only if state data on understory biomass stocks are not available.

Step (3) Calculate the Apparent Average Annual CO_2 Flux from Changes in Understory Biomass Stocks

- Calculate the difference between total understory carbon stocks in the two inventory years. A net decrease in understory carbon stocks represents carbon emissions. A net increase in understory carbon stocks represents carbon sequestration.

- Divide the difference in understory carbon stocks by the number of years between forest inventories to calculate the apparent average annual carbon flux for the period between forest inventories.

- To be consistent with the IPCC sign convention, net carbon emissions (as CO_2) should be expressed as a positive value, and net carbon uptake as a negative value.

4.1.3 Apparent Carbon Flux from the Forest Floor

Forest floor carbon stocks consist of all dead organic matter above the mineral soil horizon, including litter, humus, and other woody debris. For the purpose of carbon accounting, standing dead trees are counted as tree biomass rather than part of the forest floor stocks. The apparent carbon flux from the forest floor results from the decay of old organic matter and the deposition of additional organic matter. Using the stock approach, one estimates the net result of these processes by measuring the total forest floor carbon stocks at two points in time, and calculating the difference between these two carbon stock measurements. This calculation consists of the following steps:

Step (1) Obtain Required Data

Required Data. The basic data required to calculate the carbon stored in understory biomass consist of: (1) the total mass of forest floor organic matter on a dry-weight basis (*i.e.,* in units of short tons of dry matter); and (2) the carbon content of the forest floor organic matter on a dry-weight basis.

Data Sources.

Forest Floor Organic Matter Stocks: USFS currently does not report data on forest floor organic matter in its state forest inventories. If possible, states should use their own data on these stocks expressed on a dry-weight basis.

Forest Floor Carbon Content: If states are using their own forest floor stock data, then they will need to obtain data on the carbon content of forest floor organic matter on a dry-weight basis.

USFS Model for Estimating Forest Floor Carbon Stocks: USFS has developed a model for estimating the quantity of carbon stored in forest floor organic matter as a function of merchantable timber volume. This model is used to produce the forest floor carbon stock estimates incorporated into the *Inventory of U.S. Greenhouse Gas Emissions* *and Sinks: 1990-1997* (U.S. EPA 1999). However, USFS has not published detailed information on this model. If state data are not available, then states should refer to Table 1.4 of Birdsey (1992), which is included at the end of this section, to obtain regional data on average carbon storage in forest floor organic matter per unit of forest area. In order to apply the data from Birdsey (1992), states need to obtain information on the total forest area by forest type in two forest inventory years.

Units for Reporting Data. Data should be reported in the following units:

- Mass of forest floor organic matter: tons of dry matter (t dm)
- Organic matter carbon fraction: tons carbon per ton dry matter (t C/t dm)
- Forest area (if using USFS default data): acres

- Average storage of carbon in forest floor organic matter (if using USFS default data): short tons per acre (t C/acre)

Step (2a) Use State Data to Calculate Forest Floor Carbon Stocks in Each Forest Inventory Year (If using Step (2a), do not use Step 2(b).[11])

- For each forest inventory year, multiply the total forest floor organic matter stocks (in tons of dry matter) by the organic matter carbon content.

Step (2b) Use USFS Data to Calculate Forest Floor Biomass Carbon Stocks (If using Step (2b), do not use Step 2a.)

- For each of two forest inventory years, determine the total forest area in the state.

- For each of two forest inventory years, multiply the total forest area by the average forest floor carbon content. Refer to Table 1.4 from Birdsey (1992) at the end of this section for default values.

Step (3) Calculate the Apparent Average Annual CO_2 Flux from Changes in Forest Floor Carbon Stocks

- Calculate the difference between total forest floor carbon stocks in the two inventory years. A net decrease in forest floor carbon stocks represents carbon emissions. A net increase in forest floor carbon stocks represents carbon sequestration.

- Divide the difference in forest floor carbon stocks by the number of years between forest inventories to calculate the apparent average annual carbon flux for the period between forest inventories.

[11] Use Step (2b) only if state data on forest floor organic matter stocks are not available.

- To be consistent with the IPCC sign convention, net carbon emissions (as CO_2) should be expressed as a positive value, and net carbon uptake as a negative value.

4.1.4 Apparent Carbon Flux from Soil

The flux of CO_2 from forest soils varies according to forest type, land use, severity and frequency of disturbance, and climate. Using the stock approach, one estimates the net CO_2 flux from soils by measuring the total soil carbon stocks at two points in time, and calculating the difference between these two carbon stock measurements. This calculation consists of the following steps:

Step (1) Obtain Required Data

Required Data. The data required are (1) forest areas broken down by forest type and land-use activity, and (2) soil carbon contents per unit of forest area by forest type and land-use activity.

Data Sources.

> **Soil Carbon Stocks:** USFS currently does not report data on soil carbon stocks in its state forest inventories. If possible, states should use their own data on soil carbon stocks. IPCC default data for soil carbon contents of tropical and temperate forests in the Americas are presented in Table 10.4-6 under the flow approach below.
>
> **USFS Model for Estimating Soil Carbon Stocks:** USFS has developed a model for estimating soil carbon stocks as a function of merchantable timber volume. This model is used to produce the soil carbon stock estimates incorporated into the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1997* (U.S. EPA 1999). However, USFS has not published detailed information on this model. If state data are not available, then states should refer to Table 2.2 of Birdsey (1992), which is included at the end of this section, to obtain state data on average soil carbon stocks per unit of forest area. In order to apply the data from Birdsey (1992), states need to obtain information on the total forest area by forest type in two forest inventory years.

Units for Reporting Data. Data should be reported in the following units:

- Soil carbon stocks: short tons of carbon (t C)
- Forest area (if using USFS default data): acres
- Soil carbon content (if using USFS default data): short tons per acre (t C/acre)

Step (2) Calculate Soil Carbon Stocks in Each Forest Inventory Year

- For each of two forest inventory years, obtain data on total forest area in the state broken down by forest type and land use.

- For each of two forest inventory years, multiply the area of each forest type (by land use) by the average soil carbon content for that forest type and land use. Refer to Table 2.2 from Birdsey (1992) at the end of this section for default soil carbon contents by state.[12]

Step (3) Calculate the Apparent Average Annual CO_2 Flux from Changes in Soil Carbon Stocks

- Calculate the difference between total soil carbon stocks in the two forest inventory years. A net decrease in soil carbon stocks represents carbon emissions. A net increase in forest floor carbon stocks represents carbon uptake.

- Divide the difference in soil carbon stocks by the number of years between forest inventories to calculate the apparent average annual carbon flux for the period between forest inventories.

- To be consistent with the IPCC sign convention, net carbon emissions (as CO_2) should be expressed as a positive value, and net CO_2 uptake as a negative value.

4.1.5 Net CO_2 Flux from Land-Use Change and Forestry

The net CO_2 flux from land-use change and forestry is the sum of the apparent carbon fluxes from each of the four ecosystem components (*i.e.*, trees, understory, forest floor, and soil). To be consistent with the IPCC sign convention, net carbon emissions should be expressed as a positive value, and net carbon uptake as a negative value.

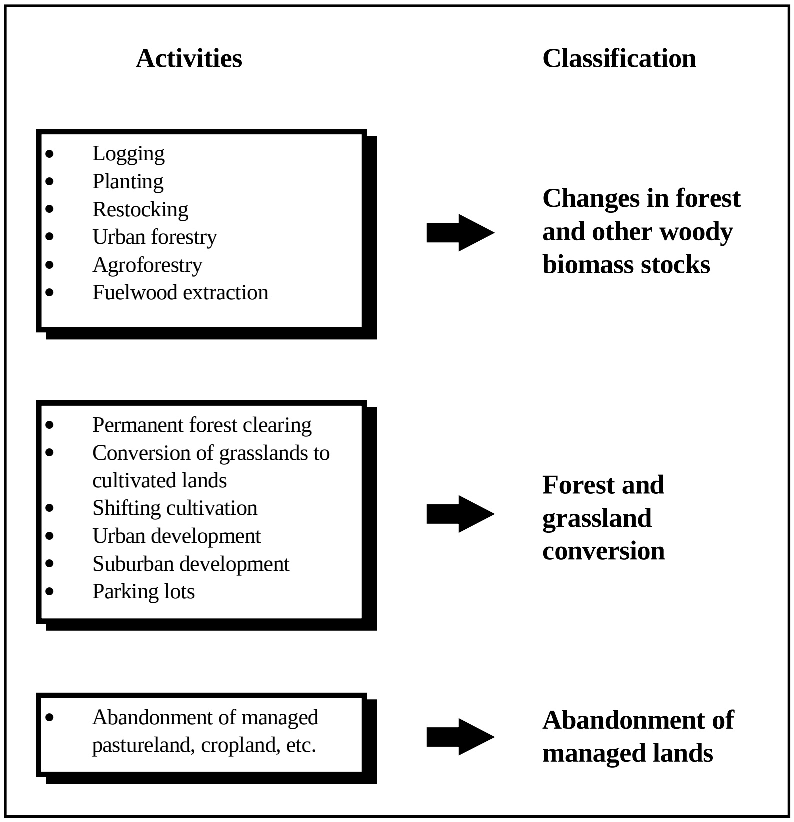
4.2 FLOW APPROACH

This section is divided into three parts, each of which reflects a general category of land-use change and forest management activities. These three parts (presented in Figure 10.4-1 with their associated activities) are as follows:

- **Changes in Forests and Other Woody Biomass Stocks:** The most significant effects of human interactions with existing forests are considered in this single broad category, which includes commercial management and logging for forest products, replanting after logging or other forest timber removal, the harvest of fuelwood, and the establishment and operation of forest plantations as well as planting trees in urban, suburban, or other non-forest locations.

[12] Care should be taken when applying the default soil carbon data in Birdsey (1992). Soil carbon content is largely dependent on land-use. In order to calculate soil carbon fluxes from the loss of forest area, it may be necessary to obtain information on the current use of the deforested land, since a loss of forest area does not necessarily imply the loss of all soil carbon stocks in that area. For example, the conversion of forest to pasture land is likely to result in CO_2 emissions from the soil without resulting in the complete depletion of soil carbon stocks.

Figure 10.4-1. Land-Use Change and Forestry Activities Covered in the Flow Approach



- **Forest and Grassland Conversion:** This category includes the conversion of forest and grasslands to pasture, croplands, or other managed uses as well as to shopping malls, parking lots, and suburban communities. These activities can significantly change the carbon stored in biomass and in soils.

- **Abandonment of Managed Lands:** Lands that had been managed previously (*i.e.*, croplands, pasture) and that are abandoned and allowed to regrow naturally, without any human interference, can re-accumulate significant amounts of carbon in their biomass and soils. This category includes previously managed lands that are regrowing naturally into their prior grassland or forest conditions.

4.2.1 Carbon Flux from Changes in Forests and Other Woody Biomass Stocks (Worksheet 10.4-9)

This category as used in these basic calculations is very broad, potentially including a wide variety of land uses and management practices. This discussion focuses heavily on changes in forests, which account for the largest component of annual changes in biomass stocks in the U.S. However, other types of biomass, such as non-forest trees (*e.g.,* in towns and cities) and woody shrubs on grasslands should be included if a state believes these are a significant component of total changes of biomass stocks.

A basic organizing concept in the section is that all existing forests can be allocated into one of three categories:

(1) Natural, undisturbed forests, where they still exist and are in equilibrium, should not be considered either an anthropogenic source or sink. They should, therefore, be excluded from state inventory calculations.

(2) Forests regrowing naturally on abandoned lands are a net carbon sink attributable to past human activities and are accounted for as discussed in the section on emissions from abandoned lands. While current regrowth is considered a response to past anthropogenic activity, “abandoned lands” are by definition assumed not to be subject to ongoing human intervention after abandonment.

(3) All other types of forests are included in the changes in forests and other woody biomass stocks category. That is, any forest which experiences periodic or ongoing human intervention that affects carbon stocks should be included here. In the basic calculations, the focus is primarily on a few types of human interactions with forests which are believed to result in the most significant fluxes of carbon. State experts are encouraged, however, to estimate emissions for any activity related to existing forests which is considered to result in significant carbon emissions or removals and for which necessary data are available.

Some of the activities in the changes in forests or other woody biomass stocks category which can potentially produce significant carbon fluxes are:

- management of commercial forests -- including logging, selective thinning, restocking, etc., as practiced by commercial forest products industries;
- establishment and management of commercial plantations[13];
- other afforestation or reforestation programs; and
- informal non-commercial fuelwood, timber, and other wood harvest.

This category also includes trees which may not traditionally be considered part of forests, such as urban trees, trees planted along highways, etc. These dispersed trees do not contribute greatly to carbon fluxes to or from the atmosphere; however, they may be of interest to some states because of their potential use in response strategies.

[13] Plantations are forest stands that have been established artificially to produce a forest product crop.

As illustrated in the above list, the changes in forests and other woody biomass stocks category includes some tree planting activities which, strictly speaking, are land-use changes. Plantation establishment and other afforestation/reforestation programs are examples. It is recognized that this is conceptually inconsistent as the category is intended to account for ongoing interactions with existing forests. However, from a pragmatic perspective, including these activities within the category can simplify the calculations. These subcategories are land-use changes which create new forest stocks. As soon as the land-use change occurs (*i.e.*, tree planting), the new land becomes part of the changes in forests and other woody biomass stocks category which is accounted for on an annual incremental basis. The following three equations summarize the recommended method (which is presented step-by-step following this discussion):

Equation 1. Annual Biomass Carbon Uptake

$$U = \sum_f \left[\left(AP_f \ x \ GP_f \ x \ CP_f \ \right) + \left(T_f \ x \ GT_f \ x \ CT_f \ \right) \right]$$

where:

U	=	annual biomass carbon uptake (short tons of carbon per year)
AP	=	area of plantations and managed forests (# of acres)
GP	=	annual biomass growth rate (t dm/acre/yr)
CP	=	Carbon fraction for plantations and managed forests (t C/t dm)
T	=	number of trees planted (# of trees)
GT	=	annual biomass growth rate (t dm/tree/yr)
CT	=	Carbon fraction for trees planted (t C/t dm)
f	=	forest type

Equation 2. Annual Biomass Carbon Release

$$R = \sum_f \left[\left(CH_f \ x \ EF_f \right) + FW_f + OW_f - FC_f \right] x \ C_f$$

where:

R	=	annual biomass carbon release (short tons of carbon per year)
CH	=	commercial harvest (ft^3/yr)
EF	=	biomass conversion/expansion factor (t dm/ft^3)[14]
FW	=	annual fuelwood consumption (t dm/yr)
OW	=	other wood use (t dm/yr)
FC	=	wood removed during forest conversion and used as fuelwood (t dm/yr)[15]
C	=	Carbon fraction (t C/t dm)
f	=	forest type

[14] To include the decay of forest products left after harvest, the harvested amounts are adjusted in two ways: (1) the volume of biomass must first be converted to mass of dry matter; and (2) an expansion ratio is applied to account for non-commercial biomass (limbs, small trees, etc.) harvested with the commercial biomass and left to decay.

[15] For estimating annual biomass emissions, all of the harvested biomass from forests is summed and the portion of harvested material used as fuelwood is subtracted, because emissions from fuelwood are accounted for in the following section on forests and grasslands conversion. This subtraction is done to avoid double-counting emissions.

Equation 3. Net Carbon Flux from Changes in Forests and Other Woody Biomass Stocks

$$Net\ CO_2\,(tons/yr) = (R - U)$$

where:

R	=	annual biomass C release (t C/yr)
U	=	annual biomass C uptake (t C/yr)

Estimates of average annual accumulation of dry matter as biomass per acre are presented for forests naturally regrowing by broad category in Table 10.4-2. These values can be used for default values for growth rates in similarly managed forest categories if no other information is available. For forests that are more intensely managed, annual growth increments can be quite different. Values for some typical plantation species are presented in Table 10.4-3 and can be used as default values. For non-forest trees, such as urban tree planting, accounting would be done on the basis of number of trees rather than for acres of land. The calculations would be the same, except the average annual growth would be expressed in tons of dry matter per tree rather than per acre. The recommended unit of calculation is tons of dry matter (or dry biomass), and needs to be converted to carbon for emissions estimation. A general default value of 0.5 tons C/ton dry matter is recommended for all biomass calculations. If more accurate conversion values are available for the particular species, these should be used.[16]

The methodology is designed to accommodate users at several levels of detail. This is especially important in the managed forests category. Many states have highly developed forest industries that keep detailed records of existing commercial forests and forests managed by non-industrial private forest owners. In addition, the U.S. Forest Service (USFS) compiles detailed forest inventory statistics every five years. For states with adequate data, it is possible to derive from survey results aggregate values comparable to the data and assumptions used in the approach provided in this chapter, and present them in this common format.[17]

Changes in forest or other woody biomass stocks may result in net emissions of CO_2 or net sequestration of carbon in a given year in a given state. The simplest way to determine whether these changes produce net emissions or net sequestration is to compare the annual biomass growth to the annual biomass harvest. The assessment of emissions from harvested biomass should account for the end use of the biomass. Harvested wood releases carbon at rates dependent upon its method of processing and its end use. Waste wood is usually burned immediately or within a couple of years; paper usually decays in up to 5 years (although landfilling paper can result in longer-term storage of carbon and eventual release of CH_4 or CO); and lumber and durable wood products decay in up to 100 years or more. Forest harvests could result in a net uptake of carbon if the wood that is harvested is used for long-term products such as building lumber and furniture, and regrowth is relatively rapid. This may in fact become part of a mitigation strategy for some states.

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[16] For region-specific data in the U.S., see Birdsey and Heath (1993) and Birdsey (1992).
[17] For region-specific data in the U.S., see USFS (1990) and Waddell (1989).

Table 10.4-2
Average Annual Biomass Uptake by Natural Regeneration
(t dm/acre)

Region		Forest Types					
		Moist Forests		Seasonal Forests		Dry Forests	
Tropical		**0-20 yrs**	**20-100 yrs**	**0-20 yrs**	**20-100 yrs**	**0-20 yrs**	**20-100 yrs**
		3.6	0.4	2.2	0.2	1.8	0.1
Temperate		**0-20 yrs**		**20-100 yrs**			
	Evergreen	1.3		1.3			
	Deciduous	0.9		0.9			
Boreal		0.4		0.4			

Source: Derived from IPCC/UNEP/OECD/IEA (1995).
Note: Growth rates are derived by assuming that tropical forests regrow to 70 percent of undisturbed forest biomass in the first twenty years. All forests are assumed to regrow to 100 percent of undisturbed forest biomass in 100 years. Assumptions on the rates of growth in different time periods are derived from Brown and Lugo, 1990. Temperate and boreal forests actually require considerably longer than 100 years to reach the biomass density of a fully mature system. Harmon et al. (1990), for example, report carefully designed simulations indicating that a 100-year old stand of douglas fir would contain only a little over half the biomass of a 450-year old growth stand of the same species. There is also evidence that growth rates in temperate and boreal systems are more nearly linear over different age periods than is the case for tropical systems. Nabuurs and Mohren (1993) suggest that growth rates for several different species in temperate and boreal zones rise slowly and peak at ages of 30 - 55 years and decline slowly thereafter. This suggests that using the same default values for 0-20 years and 20-100 years may be a reasonable first approximation. Nabuurs and Mohren (1990) also illustrate that growth rates may vary as much as a factor of ten for stands of the same species and age, depending on site-specific conditions.

Table 10.4-3
Average Annual Accumulation of Dry Matter as Biomass in Plantations
(t dm/acre-yr)

Forest Types		Average Annual Increment in Biomass
Tropical	*Acacia* spp.	6.7
	Eucalyptus spp.	6.5
	Tectona grandis	3.6
	Pinus spp.	5.1
	Pinus caribaea	4.5
	Mixed Hardwoods	3.0
	Mixed Fast-Growing Hardwoods	5.6
	Mixed Softwoods	6.5
Temperate	Douglas Fir	2.7
	Loblolly Pine	1.8

Source: Derived from IPCC/UNEP/OECD/IEA (1995).

For the purposes of the basic calculation, however, the recommended default assumption is that all carbon removed in wood and other biomass from forests is oxidized in the year of removal. This is because new products from current harvests frequently replace existing product stocks, which are in turn discarded and oxidized. This clearly would not be accurate if relative sizes of forest product pools change significantly over time, but is considered a legitimate, conservative assumption for initial calculations. However, storage of carbon in wood products can be included in a state inventory if the state can document that existing stocks of long-term forest products are in fact increasing (or decreasing). If data permit, a state could add a component to Equation (2) to account for increases (or decreases) in forest product pools (see Table 10.4-4 for default values for recycle rates and average product lives for various forest products).

To summarize, the net growth of biomass stocks (and accumulation of carbon) depends on the type of biomass stock and the intensity and type of management. Well managed commercial forests would, over the long term, be expected to have net emissions close to zero. In many cases, where historically cleared areas are regrowing under commercial management, the forest areas act as a sink. If forests are logged or harvested at a rate which exceeds regrowth, then there is a net loss of carbon.

Table 10.4-4 Average Lifetimes for Selected Forest Products

Final End-Use	Single-Use Life	Recycle Rate	Adjusted Life in Use
1-Family House	60	0.030	61.9
Multi-Family House	50	0.030	51.5
Mobile Home	12	0.107	13.4
Residential Maintenance and Repair	30	0.107	33.6
Non-residential Construction	67	0.030	69.1
Manufacturers	12	0.107	13.4
Shipping	6	0.107	6.7
Other Solid Wood Uses	30	0.107	33.6
Newsprint	1	0.230	1.3
Printing and Writing Paper	6	0.070	6.5
Tissue Paper	1	0.000	1
Packaging Paper	1	0.150	1.2

Source: Row and Phelps, 1991

Note: Carbon held in wood that is transformed into forest products will not be admitted to the atmosphere until the product burns or decays. To calculate the amount and timing of these emissions requires that the amount of wood allocated to each end-use and the average life-time of the forest product be determined. The table above provides the estimated average life for a single-use cycle, the recycle rate, and the adjusted average use life for 12 final end-use categories. The adjustment for recycling adds several years to the effective half-life of building materials. This adjustment has an even greater effect on the average life for most types of paper products. However, the life of paper products is considerably shorter than that of durable wood products.

A step-by-step description follows; the steps are also shown in Worksheet 10.4-9.

Step (1) Obtain Required Data

Required Data. The data required to calculate CO_2 flux from changes in forests and other woody biomass stocks include:

> **Forests and Other Woody Biomass Areas:** (1) Managed forests and other woody biomass areas by type; (2) annual biomass growth rates of managed areas by type; and (3) biomass carbon fraction.

Tree Planting: (1) Number of trees planted in afforestation and other tree planting activities by type; (2) annual biomass growth rates of planted trees; and (3) biomass carbon fraction.

Biomass Harvest: (1) Annual commercial harvest; (2) biomass conversion/expansion factor[18]; (3) fuelwood harvest; (4) other wood removals; (5) biomass carbon fraction; and (6) wood removed during forest clearing and burned as fuelwood.

Data Sources.

Forests and Other Woody Biomass Areas: The Forest Service of the U.S. Department of Agriculture (USFS) compiles forest resource data collected from periodic surveys in each state and Forest Service region, and publishes these data in tabular form. These tables include information on area, volume, removals, and timber product outputs, by state, ownership class, and species group. The most recent publications are for the years 1992 (Powell *et al.*, 1993), 1987 (Waddell *et al.*, 1989), and 1977 (USFS, 1982).

Tree Planting: There are no readily available published, national statistics on non-forest tree planting. It is recommended that states contact their state forestry department, particularly the urban forestry coordinator in this department, for this information.

Biomass Harvest: There are two approaches analysts can take to estimate wood removals:

- Use commercial harvest statistics; and
- Apply fuelwood consumption estimates from Chapter 1.

For some states, commercial statistics will give only a partial account of wood removals and using both sources of statistics may provide the most accurate picture. Sources for commercial statistics include the USFS forest resource data publications, as discussed above, and Row and Phelps (1991).[19]

Units for Reporting Data. Data should be reported in the following units:

- Forests and other woody biomass areas: number of acres
- Number of trees planted: number of trees

[18] Commercial harvest statistics are often provided in volumetric units and only account for the commercial portion of biomass. In this case, the harvested amounts must be adjusted in two ways to reflect the values needed for the emissions/uptake calculations. The volume of biomass must first be converted to mass of dry matter by applying a density. In addition, an expansion ratio must be applied to account for non-commercial biomass (limbs, small trees, etc.) harvested with the commercial biomass and left to decay or destroyed during processing.

[19] Row, C. and R.B. Phelps. 1991. "Wood Carbon Flows and Storage After Timber Harvest," in Proceedings *Forests and Global Change*. June 11-12, 1991, Arlington, VA. American Forestry Association.

- Annual biomass growth rates of forests and woody biomass areas: short tons dry matter per acre per year (t dm/acre/yr)
- Annual biomass growth rates of non-forest trees: ton dry matter per tree per year (t dm/tree/yr)
- Biomass carbon fraction: tons carbon per ton dry matter (t C/t dm)
- Annual commercial harvest: cubic feet per year (ft^3/yr)
- Biomass conversion/expansion factor: tons dry matter per cubic foot (t dm/ft^3)
- Fuelwood harvest: tons dry matter per year (t dm/yr)
- Other wood removed: tons dry matter per year (t dm/yr)
- Wood removed during forest clearing and burned as fuelwood: tons dry matter per year (t dm/yr)

Step (2) Estimate Total Carbon Content in Annual Growth of Managed Forests and Other Woody Biomass Areas (Worksheet 10.4-9, Columns A - E)

- Obtain the number of acres for each type of managed area on which biomass is accumulating, *e.g.*, plantations, managed forest areas, etc. Enter this in Column A.

- For dispersed trees (*e.g.*, urban tree planting, farm trees, etc.), enter the number of trees of each type in Column A.

- For each type of forest/woody biomass area, enter the Annual Growth Rate (in tons of dry matter per acre) in Column B. The default statistics in Table 10.4-2 or 10.4-3 may be used if state data are not available.

- For other non-forest trees, enter the Annual Growth Rate in tons of dry matter per tree per year in Column B, *i.e.*, use the average annual growth rate per tree.

- For each type of forest/woody area, multiply the Area of Forest/Biomass Stocks by the Annual Growth Rate to give Annual Biomass Increment in tons of dry matter. Enter the result in Column C.

- For non-forest trees, multiply the Number of Trees by the Annual Growth Rate to give Annual Biomass Increment in tons of dry matter. Enter in Column C.

- For each type of biomass stock, enter the Carbon Fraction of Dry Matter in Column D. The default value is 0.5 for all biomass, if specific values are not available. (See Table 1-2 of Birdsey, 1992, provided at the end of this chapter, for species-specific values for the U.S.)

- Multiply the Annual Biomass Increment by the Carbon Fraction of Dry Matter to give the Total Carbon Uptake Increment (tons carbon). Enter the result in Column E.

- Add the figures in Column E and enter the total in the Total box at the bottom of the column.

Step (3) Estimate the Amount of Biomass Harvested (Worksheet 10.4-9, Columns F - L)

- Enter the annual amount of timber harvested in the state for commercial purposes (in cubic feet) in Column F.

- Commercial wood harvest statistics are typically measured in units of cubic feet, and are often provided for the merchantable portion of biomass only (*i.e.*, commercial roundwood). When either of these conditions applies to the data for timber harvests, these data need to be converted from cubic feet of biomass to short tons of dry matter, and/or from quantity of merchantable timber harvested to quantity of all biomass harvested.

    - To convert data from cubic feet of biomass to short tons of dry matter, enter the Biomass Conversion Ratio in Column G. The default Biomass Conversion Ratio is 0.016 t dm/ft^3.
    - To expand the estimate of merchantable timber biomass to total biomass, enter the Biomass Expansion Ratio in Column G. The default Biomass Expansion Ratio is 1.75 for undisturbed forests, 1.90 for logged forests, and 2.00 for unproductive forests.
    - If both Biomass Conversion and Expansion Ratios need to be applied, enter the product of both ratios into Column G. The default Biomass Expansion/Conversion Ratio is 0.027 for undisturbed forests, 0.030 for logged forests, and 0.031 for unproductive forests.

- Multiply the amount of Commercial Harvest by the Biomass Conversion/Expansion Ratio (if necessary) to give Total Biomass Removed in Commercial Harvest in tons of dry matter. Enter the result in Column H.

- Enter Total Fuelwood Consumed annually (including wood for charcoal production) in tons dry matter in Column I.

- Enter the quantity of annual Total Other Wood Use in tons dry matter in Column J.

- Add the Total Biomass Removed in Commercial Harvest (Column H) to the Total Fuelwood Consumed (Column I) and Total Other Wood Used (Column J) to give Gross Biomass Consumption. Enter this result in Column K. Sum this column and enter the result in the Totals box at the foot of the column.

- Enter Wood Removed During Forest Clearing and Burned as Fuelwood in tons dry matter (Worksheet 2, Column G) at the bottom of Column L.

- Subtract Wood Removed During Forest Clearing (Column L) from Gross Biomass Consumed (Column K) to give Net Biomass Consumption (Column M).

Step (4) Convert Wood Harvested to Carbon Removed (Worksheet 10.4-9, Columns M - O)

- Enter the Carbon Fraction of the biomass in Column N (the general default value for live biomass is 0.5 t C/t dm).

- Multiply Total Biomass Consumption (Column M) by Carbon Fraction (Column N) to give Annual Carbon Release (in tons of carbon). Enter the result in Column O.

Step (5) Estimate Net Annual Amount of Carbon Uptake or Release (Worksheet 10.4-9, Columns O - Q)

- Subtract Annual Carbon Increment (Column O) from Total Carbon Released (Column E) to give Net Annual Carbon Uptake or Emissions. Enter the result in Column P.

- Multiply the Net Annual Carbon Uptake or Emissions (Column P), as measured in short tons, by 0.91 to give Annual CO_2 Emissions (if a positive value) or Uptake (if a negative value), measured in metric tons of carbon equivalent (MTCE). Enter the result in Column Q.

4.2.2 Carbon Flux from Forest and Grassland Conversion (Worksheets 10.4-10 through 10.4-12)

Forest and grassland conversion to permanent cropland, pasture, or suburban and urban areas can result in the release of carbon not only from the clearing of land (*i.e.*, through decay of cleared biomass) but also due to the disturbance of the carbon stored in the soil. It should be noted that in some instances, some of the biomass cleared is burned as fuelwood. This burning results in emissions of CO_2 as well as CO, CH_4, NO_X, and N_2O. The non-CO_2 emissions from this source are assumed to be accounted for in the biofuels calculations presented in Chapter 14. This part of the method accounts for CO_2 emissions from cleared biomass that is burned and decays. As in the calculations for changes in forests and other woody biomass stocks, the methodology does not include time lags associated with biomass decay. Time lags associated with soil carbon emissions, however, are included.

This category includes conversion of existing forests and natural grasslands to other land uses, including agriculture, highways, urban development, etc. As with all categories of forest management and land-use change activity, it is necessary to determine net CO_2 flux from biomass loss. The basic calculations employ the same simplifying assumption regarding biomass removals in this part as in the previous part, *i.e.*, that biomass removals replace existing stocks that are in turn oxidized. Therefore, in the calculations, biomass removals are treated like instantaneous emissions. This methodological simplification in effect accounts for current emissions due to decay of materials cleared in previous years, assuming that rates of land conversion and allocations to product pools have not changed significantly over time.

Forest and grassland conversion also results in CO_2 emissions through soil disturbance and oxidation of soil organic matter, particularly when the conversion is to cultivated lands or urban development. This is a long-term process which may continue for many years after the land-use change occurs. The basic calculations allow for estimation of current emissions from soil carbon disturbance due to current and previous land conversion through an averaging approach.

In some countries, when forests are cleared, significant amounts of the cleared biomass are burned to prepare the lands for cultivation or pasture. In addition to CO_2, this biomass burning releases CO, CH_4, N_2O and NO_x. However, this part of the method does not account for any non-CO_2 emissions from biomass burning. There are two basic reasons for omitting these emissions from the method presented here:

- Land clearing by burning is rarely practiced in the U.S. due to regulatory and practical considerations, therefore, emissions from this source are assumed to be zero.

- Any non-CO_2 emissions that result from this source are assumed to be due to the use of cleared biomass as fuelwood in fireplaces, woodstoves, etc. These emissions are captured in the calculations for wood combustion presented in chapter 14.

Carbon emissions (as CO_2) due to forest clearing and grassland conversion are calculated through a sequence of steps that estimate:

- the net change in aboveground biomass carbon;
- current emissions from loss (decay and burning) of net biomass cleared; and
- current releases of carbon from soils due to conversions over the previous 25 years.

This method is summarized in equations 4 through 6 below.

Equation 4. Carbon Released from Loss of Biomass

$$C\ Released\ as\ Loss\ of\ Aboveground\ Biomass\ (t\ C/yr) = \sum_f \left[AA_f \times \left(BC_f - AC_f\right)\right] \times CF_f$$

where:

AA	=	annual area converted (acres/yr)
BC	=	aboveground biomass before conversion (t dm/acre)
AC	=	aboveground biomass after conversion (t dm/acre)
CF	=	carbon fraction of aboveground biomass (t C/t dm)
f	=	forest/grassland type

Equation 5. Carbon Released from Soil

$$Soil\ Carbon\ Released\ (t\ C/yr) = \sum_f \left[\left(AA\text{-}25_f \ x\ CC_f \right) x\ CF\text{-}25_f \right]$$

where:

AA-25	=	average annual area converted over 25-year period (acres/yr)
CC	=	carbon content of soil before conversion (t/acre)
FC-25	=	fraction of carbon released over 25-year period (t C/yr)
f	=	forest/grassland type

Equation 6. Total Carbon Released

$$Total\ Annual\ Carbon\ Released\ (1{,}000\ t\ C/yr) = \sum_f \left(BL_f + SL_f \right)$$

where:

BL	=	emissions from biomass loss (t C/yr)
SL	=	emissions from soil (t C/yr)
f	=	forest/grassland type

First, the amount of aboveground biomass affected by conversion in the emissions inventory year is calculated by multiplying the annual forest area converted to other land uses by the net change in aboveground biomass. This calculation is carried out for each relevant forest/grassland type. The net change is the difference between the density (tons dry matter per acre) of aboveground biomass on that forest/grassland prior to conversion, and the density of aboveground biomass after clearing. The after clearing value includes the biomass that regrows on land in the year after conversion and any original biomass that was not completely cleared. Default data for the biomass contained in tropical and temperate forests are provided below in this section.

It is suggested that the annual carbon flux associated with the loss of soil carbon following forest clearing or grassland conversion is calculated using a 25-year time horizon to account for delayed releases of soil carbon. The historical release of carbon from soil equals (1) the average annual acreage of land clearing, times (2) the change in carbon stock in soil between the original land use and the new use (*e.g.*, 25-year old pasture or urban development). For simplicity, it is assumed that the soil carbon release is linear over the 25-year period.

The annual rate of soil carbon loss would be the total change in soil carbon from before conversion to after conversion, divided by 25. The currently available information on soil carbon changes after conversion relates primarily to temperate and boreal forests and temperate grasslands. Research indicates that approximately 50 percent of the soil carbon in the active layer (roughly the top 3 feet) is lost over a 50-year period, with most of this loss occurring in the first 25 years. However, these values are highly uncertain. The actual rate of soil carbon loss in a particular area of agricultural land, for example, is a function of the specific agricultural use of, and management practices on, the land. However, the general values above can be used as a default for initial calculations, if more accurate information or measurements are not available. This would imply that the annual rate of soil carbon loss would be 2 percent (50 percent/25 yrs).

The contemporary flux associated with past land-use change could be calculated by multiplying the number of acres of land converted in each of the previous 25 years by an annual per acre loss in soil carbon and summing over all years. Alternatively, the average annual historical conversion rate over a 25-year period could be multiplied by the annual loss rate times 25. The average rate of conversion is simply the total acres converted over the period divided by 25 years. The division by 25 and multiplication by 25 cancel each other and can be ignored. The recommendation is to use average values for the rate of land conversion, soil carbon content, and portion of the soil carbon lost over time. This averaging approach is used in the method to simplify the calculations and to reduce data requirements. Average values for soil carbon in forest systems are provided below in this section.[20]

Step (1) Obtain Required Data

Required Data: The following data are required to estimate emissions from forest and grassland conversion:

- Annual forest and/or grassland areas converted by type; in the inventory year and a 25-year average
- Aboveground biomass per area of forest and/or grassland by type
- Aboveground biomass per area of replacement vegetation
- Carbon in soil per unit forest and/or grassland area by type
- Fraction of carbon released from soil following forest and grassland conversion

Data Sources: The Natural Resource Conservation Service of the U.S. Department of Agriculture (USDA/NRCS) conducts an inventory of all non-Federal rural lands every five years. This *National Resources Inventory* (NRI) contains land-use change data by state for croplands, pasturelands, rangelands, forest lands, and minor land uses. The latest NRI, for the year 1992, contains land-cover change matrices by state for the 1982 - 1992 period. These matrices not only provide the total change in each land use over the period, but also the dynamics of each change (*e.g.,* of the total 1982 - 1992 conversion of cropland, how much was to pastureland and how much was to forest land). However, the NRI data only cover non-federal lands, so a large portion of the U.S. forest lands are not included in this data base.

Units for Reporting Data: Data should be collected in the following units:

- Annual area of forest and grassland converted in the inventory year and averaged over 25 years: acres per year
- Aboveground biomass: tons dry matter per acre (t dm/acre)
- Carbon in soil: tons carbon per acre (t C/acre)

[20] For region-specific data in the U.S. see Birdsey (1992).

Step (2) Estimate CO_2 Released by Decay of Net Cleared Biomass (Worksheet 10.4-10, Columns A - I)

- Enter the figures for Annual Area Converted (in inventory year) in acres per year for each forest/grassland type in Column A.

- Enter the Aboveground Biomass Density in tons of dry matter per acre (t dm/acre) before conversion in Column B. Default values are provided in Tables 10.4-5 and 10.4-6.

Table 10.4-5
Aboveground Dry Matter in Tropical Forests in the Americas
(t dm/acre)

Moist Forest		Seasonal Forest		Dry Forest	
Primary	**Secondary**	**Primary**	**Secondary**	**Primary**	**Secondary**
103	85	62	54	27	11

Source: Derived from IPCC/UNEP/OECD/IEA (1995)

Table 10.4-6
Aboveground Dry Matter in Temperate and Boreal Forests
(t dm/acre)

	Temperate Forests		Boreal Forests
	Evergreen	**Deciduous**	
Primary	132	112	74
Secondary	98	78	54

Source: Derived from IPCC/UNEP/OECD/IEA (1995)

- Enter the Aboveground Biomass Density in tons of dry matter per acre (t dm/acre) after conversion in Column C. This figure includes any biomass not fully cleared (default value = 0) and the biomass regrowth in agricultural use (the default value is 4.5 t dm/acre) or other use subsequent to clearing.

- Subtract the value in Column C from the value in Column B to produce Net Change in Biomass Density in tons of dry matter per acre. Enter the results in Column D.

- Multiply the Annual Area Converted (Column A) by the Net Change in Biomass Density (Column D) to calculate the Annual Loss of Biomass (aboveground) for each forest/grassland type in tons of dry matter. Enter the results in Column E.

- Enter the Fraction of Biomass Used as Fuelwood in Column F.

- Multiply Fraction of Biomass Used as Fuelwood (Column F) by the Average Annual Loss of Biomass (Column E) to determine Amount of Annual Loss of Biomass Used as Fuelwood in tons dry matter. Enter this result in Column G. (This figure is used in Step (3) of the calculations for changes in forests and woody biomass stocks).

- Enter the Carbon Fraction in Aboveground Biomass in Column H (default fraction 0.5 t C/t dm).

- Multiply the Annual Loss of Biomass (Column E) by the Carbon Fraction (Column H) to calculate Carbon Released from Loss of Aboveground Biomass. Enter the figures in Column I.

- Add the figures in Column I and enter the total in the Subtotal box at the bottom of the column.

Step (3) Estimate Carbon Released by Soil (Worksheet 10.4-11, Columns A - E)

- Enter the Average Annual Forest/Grassland Converted over the last 25 years in acres per year in Column A.

- Enter the Soil Carbon Content Before Conversion by forest or grassland type in Column B. See Table 10.4-7 for forest soil defaults. Defaults for grasslands are 27 t C/acre for tropical zones and 31 t C/acre for temperate zones.

Table 10.4-7
Carbon in Forest Soils in the Americas
(tons C/acre)

Tropical Forests	Moist 51	Seasonal 45	Dry 27
Temperate Forests Primary Secondary	Evergreen 60 54	Deciduous 60 54	
Boreal Forests Primary Secondary	92 83		

Source: Derived from IPCC/UNEP/OECD/IEA (1995).
Note: See Table 1.3 of Birdsey (1992) for region-specific values of forest soil carbon in the U.S.

- Multiply the Average Annual Forest/Grassland Converted (Column A) by the Carbon Content of Soil Before Conversion (Column B) to calculate the Total Annual Potential Soil Carbon Loss in tons carbon per year. Enter the result in Column C.

- Enter the Fraction of Carbon Released over 25 years in Column D (default fraction 0.5).

- Multiply the Total Annual Potential Soil Carbon Losses by the Fraction of Carbon Released to give Carbon Release from Soil in tons carbon per year. Enter the result in Column E.

- Add the totals for each forest/grassland type and enter the total in the Subtotal box at the bottom of the column.

Step (4) Estimate Total Carbon Emissions from Forest and Grassland Conversion (Worksheet 10.4-12, Columns A - D)

- Enter the Emissions from Biomass Loss (contained in the Subtotal box of Column I in Worksheet 10.4-10) in Column A.

- Enter Long-Term Emissions from Soil Carbon (contained in the Subtotal box of Column E in Worksheet 10.4-11) in Column B.

- Add the Figures in Columns A and B to Calculate Total Annual Carbon Release (in the inventory year from clearing over a 25 year period). Enter the result in Column C.

- Multiply the Total Annual Carbon Release (as measured in short tons) by 0.91 to convert to units of metric tons of carbon equivalent (MTCE). Enter the result in Column D.

4.2.3 Carbon Flux from Abandonment of Managed Lands (Worksheet 10.4-13)

This section deals with emissions/uptake from the abandonment of managed lands. Managed lands include:

- cultivated lands, and
- pasture (*e.g.*, lands used for grazing animals).

Carbon accumulation on abandoned lands is sensitive to the type of natural ecosystem (forest type or grasslands) which is regrowing. Therefore, data on abandoned lands regrowing should be obtained by type. For lands that are growing into grasslands, the default assumption is that net accumulation of aboveground biomass is zero. Only soil carbon is calculated in that case. Also, because regrowth rates usually decline after a time, the periods considered are land abandoned during the 20 years prior to the inventory year (*i.e.*, between 1970 and 1990); and land abandoned between 20 and 100 years prior to the inventory year (*i.e.*, between 1890 and 1970).

When managed lands are abandoned, carbon may or may not re-accumulate on the land. Abandoned areas therefore are split into those which re-accumulate carbon and those which do not regrow or which continue to degrade. Only natural lands that are regrowing are explicitly included in the calculations since lands that do not regrow do not accumulate carbon and abandoned lands that degrade are not believed to be a significant source of emissions. However, if users of the method believe that degrading lands contribute significantly to emissions, and data are available with which to estimate emissions, degrading lands can be included in the calculations.

If managed lands, *e.g.*, croplands and pastures, are abandoned, carbon may re-accumulate on the land and in the soil. The response of these converted systems to abandonment depends on a complexity of issues including soil type, length of time in pasture or cultivation, previous management practices, and the type of original ecosystem of the land. Some abandoned lands my be too infertile, saline, or eroded for regrowth to occur. In this case, either the land remains in its current state or it may further degrade and lose additional organic material (*i.e.*, carbon in the biomass and the soils). Therefore, to calculate changes in carbon flux from this activity, the area abandoned should first be split into parts: lands that re-accumulate carbon naturally, and those that do not or perhaps even continue to degrade.

Abandoned lands must be evaluated in the context of the various natural ecosystems originally occupying them (*e.g.*, moist forest, dry forest, grassland). In addition, the effect of previous patterns of management prior to abandonment should be considered while recognizing the desire for simplicity and practicality of the method. The process of recovery of aboveground biomass is generally slower than the human-induced oxidation of biomass. With this in mind, it is recommended that abandoned lands be evaluated in two time horizons: a 20-year horizon to capture the more rapid growth expected after abandonment; and from 20 years after abandonment up to 100 years. The method is divided into five steps and is summarized in the equations below. Note that completing equations 9 and 10 is optional, and should only be considered if data are readily available. The equations are followed by a discussion and a step-by-step description.

Equation 7. Carbon Uptake from Aboveground Biomass (Last 20 yrs.)

$$\textit{Annual Carbon Uptake for Aboveground Biomass}\ (t\ C/yr) = \sum_e (AY_e\ x\ RB_e\ x\ C_e)$$

where:

AY	=	total area abandoned and regrowing during last 20 years (acres)
RB	=	annual rate of aboveground biomass accumulation (t dm/acre/yr)
C	=	Carbon fraction of biomass (t C/t dm)
e	=	regrowth ecosystem type

Equation 8. Carbon Uptake from Soils (Last 20 yrs.)

$$\textit{Annual Carbon Uptake for Soils}\ (t\ C/yr) = \sum_e (AY_e\ x\ RS_e)$$

where:

AY	=	total area abandoned and regrowing during last 20 years (acres)
RS	=	annual rate of C uptake in soils (t C/acre/yr)
e	=	regrowth ecosystem type

Equation 9. Carbon Uptake from Aboveground Biomass (Last 21 - 100 yrs.)

$$Annual\ Carbon\ Uptake\ for\ Aboveground\ Biomass\ (t\ C/yr) = \sum_e (AO_e\ x\ RB_e\ x\ C_e)$$

where:

AO	=	total area abandoned and regrowing during last 21 to 100 years (acres)
RB	=	annual rate of aboveground biomass accumulation (t dm/acre/yr)
C	=	carbon fraction of biomass (t C/t dm)
e	=	regrowth ecosystem type

Equation 10. Carbon Uptake from Soils (Last 21 - 100 yrs.)

$$Annual\ Carbon\ Uptake\ for\ Soils\ (t\ C/yr) = \sum_e (AO_e\ x\ RS_e)$$

where:

AO	=	total area abandoned and regrowing during last 21 to 100 years (acres)
RS	=	annual rate of C uptake in soils (t C/acre/yr)
e	=	regrowth ecosystem type

Equation 11. Total Carbon Uptake

$$Total\ Carbon\ Uptake\ on\ Abandoned\ Lands\ (t/yr) = (A + B + C + D)$$

where:

A	=	annual C uptake in aboveground biomass on land abandoned within last 20 years (t C/yr) (Step 1)
B	=	annual C uptake in soils on land abandoned within last 20 years (t C/yr) (Step 2)
C	=	annual C uptake in aboveground biomass on land abandoned within last 21 to 100 years (t C/yr) (Step 3)
D	=	annual C uptake in soils on land abandoned within last 21 to 100 years (t C/yr) (Step 4)

In the basic calculation (as presented above), only those lands that begin to return to their previous natural state are considered. Those that remain constant with respect to carbon flux can be ignored. Likewise, the CO_2 flux to the atmosphere for those lands that continue to degrade is likely to be small, and hence is ignored in these basic calculations.

Table 10.4-2 presents estimates of average annual aboveground biomass accumulation in vegetation in various regrowing forest ecosystems following abandonment of cultivated land or pasture. These general growth rates should be considered crude approximations as applied to the particular lands regrowing in a given state. Accumulation of aboveground biomass can be converted to carbon using a general default conversion value for biomass of 0.5 tons carbon per ton dry matter.

If lands are regenerating to grasslands, then the default assumption is that no significant changes in aboveground biomass occur (this can be varied based on locally available data). Default rates for soil carbon uptake for both forests and grasslands can be derived from the expected soil carbon values for fully restored natural systems and some simple assumptions. In temperate and boreal systems, it can be assumed that soil carbon accumulates linearly for some base value (*e.g.,* 50-70 percent of original stocks). Table 10.4-7 provides default soil carbon values for these systems. (Soil carbon changes in tropical systems are poorly understood and can be included or ignored in the basic calculations at the discretion of state experts. Experts may consult Birdsey (1992) for region-specific estimates of soil carbon).

The base value at the start of the re-accumulation process in soils would depend on the average amount of time that cleared lands had been used for agricultural purposes before abandonment and on management practices utilized during the agricultural period. Based on simple default assumptions for soil carbon losses from forest clearing, experts can calculate the level to which soil carbon would have fallen during the agricultural use period. The default assumption is that after 20 years, soil carbon would have fallen to 50 percent of the pre-clearing value (*i.e.,* 2 percent per year linear average change).

Available evidence indicates that, on average, soil carbon re-accumulates in soils after abandonment, at a slower rate than it is lost under cultivation. In the forest clearing calculations the default assumption is that soil carbon is lost at an average rate of 2 percent of the original carbon content per year. If no detailed information is available, a default assumption could be that the soil accumulation occurs linearly at roughly one-half this rate after abandonment.

A step-by-step description follows; the steps are also shown in Worksheet 10.4-9.

Step (1) Obtain Required Data

Required Data. To calculate uptake from abandoned lands, the following data are necessary:

> **For Years Between 1970 and 1990:** (1) total area abandoned during last 20 years that is regenerating; (2) annual average biomass accumulation per unit area regenerating; (3) average annual soil C accumulation per unit area regenerating; and (4) the carbon fraction of replacement biomass.
>
> **For Years Between 1890 and 1970 (optional):** (1) total area abandoned between 20 and 100 years that is regenerating; (2) average annual biomass accumulation per unit area regenerating; (3) average annual soil C accumulation per unit area regenerating; and (4) the carbon fraction of replacement biomass.

Data Source. There are no readily available national statistics with which to estimate fluxes from this source, although the NRI data that were discussed in the previous section may be useful. States could contact their NRCS State offices to obtain detailed state-level information.

Units for Reporting Data. Data should be reported in the following units:

For Years Between 1970 and 1990:

- Total area abandoned during last 20 years that is regenerating in acres;
- Annual average biomass accumulation per unit area regenerating in tons of dry matter per acre per year (t dm/acre/yr);
- Average annual soil C accumulation per unit area regenerating in tons of carbon per acre per year (t C/acre/yr);
- Carbon fraction of replacement biomass in tons of carbon per ton of dry matter (t C/t dm).

For Years Between 1890 and 1970 (optional):

- Total area abandoned between 20 and 100 years that is regenerating in acres;
- Average annual biomass accumulation per unit area regenerating in tons of dry matter per acre per year (t dm/acre/yr);
- Average annual soil C accumulation per unit area regenerating in tons of carbon per acre per year (t C/acre/yr); and
- Carbon fraction of replacement biomass in tons of carbon per ton of dry matter (t C/t dm).

Step (2) Calculate Annual Carbon Uptake in Aboveground Biomass (Land Abandoned in the Last Twenty Years) (Worksheet 10.4-13, Columns A - E)

- Enter the Total Area Abandoned during the last twenty years that is regrowing (in acres) in Column A.

- Enter the Annual Rate of Aboveground Biomass Growth (in tons dry matter per acre per year) in Column B. See Table 10.4-2 for default values.

- Multiply the Total Area Abandoned and Regrowing (Column A) by the Annual Rate of Aboveground Biomass Growth (Column B) to give the Annual Aboveground Biomass Growth (in tons dry matter). Enter the result in Column C.

- Enter the Carbon Fraction of Aboveground Biomass in Column D (Default is 0.5 t C/t dm)

- Multiply Annual Aboveground Biomass Growth (Column C) by the Carbon Fraction of Aboveground Biomass (Column D) to give the Annual Carbon Uptake in Aboveground Biomass. Enter the result in Column E.

- Add the figures in Column E and enter the total in the Subtotal box at the bottom of the column.

Step (3) Calculate Annual Carbon Uptake in Soils (Land Abandoned in Last Twenty Years) (Worksheet 10.4-14, Columns F - G)

- Enter Annual Rate of Uptake of Carbon in Soils (in tons of carbon per acre per year) in Column F. Default values for soil carbon in temperate and boreal forests are provided in Table 10.4-8. No values are available for tropical systems or grasslands.

Table 10.4-8
Annual Soil Carbon Accumulation in Temperate and Boreal Forests
(tons C/acre/yr)

Temperate		Boreal
Evergreen	Deciduous	
0.6	0.6	0.9

Source: Derived from IPCC/UNEP/OECD/IEA (1995).

- Multiply the Total Area Abandoned and Regrowing (Column A) by the Annual rate of Uptake of Carbon in Soils (Column F) to give the Total Annual Carbon Uptake in Soils (in tons carbon per year). Enter the results in Column G.
- Add the figures in Column G and enter the total in the Subtotal box at the bottom of the column.

Step (4) Calculate Annual Carbon Uptake in Aboveground Biomass (Land Abandoned Between Twenty and a Hundred Years) (Worksheet 10.4-14, Columns H - L)
(Optional)

- Enter the Total Area Abandoned for twenty to a hundred years (in acres) in Column H.
- Enter the Annual Rate of Aboveground Biomass Growth (in tons of dry matter per acre per year) in Column I. See Table 10.4-2 for default values.
- Multiply the Total Area Abandoned (Column H) by the Annual Rate of Aboveground Biomass Growth (Column I) to give the Annual Aboveground Biomass Growth (in tons dry matter per year). Enter the result in Column J.
- Enter the Carbon Fraction of Aboveground Biomass in Column K (default fraction 0.5 t C/t dm).
- Multiply the Annual Aboveground Biomass Growth (Column J) by the Carbon Fraction of Aboveground Biomass (Column K) to give the Annual Carbon Uptake in Aboveground Biomass. Enter the result in Column L.

- Add the figures in Column L and enter the total in the Subtotal box at the bottom of the column.

Step (5) Calculate Annual Carbon Uptake in Soils (Land Abandoned between Twenty and a Hundred Years) (Worksheet 10.4-16, Columns M and N) (Optional)

- Enter the Annual Rate of Uptake of Carbon in Soils (in tons of carbon per acre per year) in Column M. Default values are 0.5 times the values in Table 10.4-8.

- Multiply the Total Area Abandoned (Column H) by the Annual Rate of Uptake of Carbon in Soils (Column M) to give the Total Annual Carbon Uptake in Soils (in tons carbon per year). Enter the results in Column N.

- Add the figures in Column N and enter the total in the Subtotal box at the bottom of the column.

Step (6) Calculate Total CO_2 Uptake from Abandoned Lands (Worksheet 10.4-16, Columns E, G, L, N, O and P)

- Add the subtotals from Columns A, G, L and N and enter the Total Carbon Uptake from Abandoned Lands in Column O.

- Multiply the Total Carbon Uptake (as measured in short tons) by 0.91 to convert the units to metric tons of carbon equivalent (MTCE). Enter the result in Column P. For consistency with other emission/uptake categories, it is necessary to reverse the sign of these results, so that CO_2 uptake by abandoned lands is expressed as a negative value.

4.2.4 Carbon Flux from All Forest Management and Land-Use Activities (Worksheet 10.4-14)

To calculate total carbon emissions/uptake from all forest management and land-use activities within a state, an analyst must sum the figures estimated in the previous three sections.

Specifically:

Equation 12. Net Carbon Emissions/Uptake from Forests and Land-Use Change

$$\textit{Total Carbon Emissions/Uptake}\left(\textit{MTCE/yr}\right) = \textit{Step 1} + \textit{Step 2} + \textit{Step 3}$$

where:

Step 1: Net carbon emissions/uptake from changes in forests and woody biomass stocks (MTCE/yr)
Step 2: Net carbon emissions from forest and grassland conversion (MTCE/yr)
Step 3: Net carbon emissions/uptake from abandoned lands (MTCE/yr)

- Enter net carbon emissions/uptake from changes in forests and woody biomass stocks (figure from Worksheet 10.4-9, Column Q) in Column A (in MTCE/yr).

- Enter net carbon emissions from forest and grassland conversion (figure from Worksheet 10.4-12, Column D) in Column B (in MTCE/yr).

- Enter net carbon emissions/uptake from abandoned lands (figure from Worksheet 10.4-13, Column P) in Column C (in MTCE/yr).

- Sum Columns A, B, and C to obtain net carbon emissions/uptake from all forest management and land-use activities in a state. Enter the result in Column D (in MTCE/yr). If the figure is positive, then this source category is counted as a net source of CO_2. If the figure is negative, then this source category is counted as a net sink of CO_2 and the net amount of CO_2 sequestered can be subtracted from the amount of CO_2 emitted in a state.

Worksheet 10.4-9: Changes in Forests and Woody Biomass Stock

Forest Type	***Column A*** Area of Biomass/Forest Stocks (acres)	***Column B*** Annual Growth Rate (t dm/acre/yr)	***(A × B)*** ***Column C*** Annual Biomass Increment (t dm/yr)	***Column D*** Carbon Fraction of Dry Matter (t C/t dm)	***(C × D)*** ***Column E*** Total Carbon Uptake Increment (t C/yr)
Non-Forest Trees	***Column A*** Number of Trees (trees)	***Column B*** Annual Growth Rate (t dm/tree/yr)	Follow the Column Headings Above		
				Total:	

Worksheet 10.4-9: Changes in Forests and Woody Biomass Stocks (Continued)

Harvest Categories	***Column F*** Amount of Commercial Timber Harvested (ft^3/yr)	***Column G*** Biomass Conversion/ Expansion Ratio (t dm/ft^3)	***(F × G)*** ***Column H*** Total Biomass Removed in Commercial Harvest (t dm/yr)	***(Column G, Worksheet 10.4-10)*** ***Column I*** Fuelwood Consumed (t dm/yr)	***Column J*** Total Other Wood Used (t dm/yr)	***(H + I + J)*** ***Column K*** Gross Biomass Consumed (t dm/yr)	***Column L*** Wood Removed from Forest Clearing (t dm/yr)	***(K - L)*** ***Column M*** Net Biomass Consumption (t dm/yr)
Totals:								

Worksheet 10.4-9: Changes in Forests and Woody Biomass Stocks (Continued)

Column N Carbon Fraction of Dry Matter (t C/t dm)	***($M \times N$)*** ***Column O*** Annual Carbon Released (t C/yr)	***(O - E)*** ***Column P*** Net Annual Carbon Uptake or Release (t C/yr)	***($P \times 0.91$)*** ***Column Q*** Annual Carbon Emissions or Uptake (MTCE/yr)

Worksheet 10.4-10: Forest and Grassland Conversion

Land Types			**Column A** Annual Area Converted (acres/yr)	**Column B** Above-ground Biomass Density Before Conversion (t dm/ acre)	**Column C** Above-ground Biomass Density After Conversion (t dm/acre)	*(B-C)* **Column D** Net Change in Biomass Density (t dm/acre)	*(A × D)* **Column E** Annual Loss of Above-ground Biomass (t dm/yr)	**Column F** Fraction of Biomass Used as Fuelwood	*(E × F)* **Column G** Amount of Annual Loss of Biomass Used as Fuelwood (t dm/yr)	**Column H** Carbon Fraction in Above-ground Biomass (t C/t dm)	*(E × H) × 0.91* **Column I** Carbon Released from Loss of Above-ground Biomass (MTCE/yr)
Tropical	Moist Forest	Primary									
		Secondary									
	Seasonal Forests	Primary									
		Secondary									
	Dry Forests	Primary									
		Degraded									
Temperate	Evergreen	Primary									
		Secondary									
	Deciduous	Primary									
		Secondary									
Boreal	Primary										
	Secondary										
Grassland											
Other											
										Subtotal:	

Worksheet 10.4-11: Forest and Grassland Conversion

Land Types			***Column A*** Average Annual Forest/Grassland Converted (25-year average) (acres/yr)	***Column B*** Carbon Content of Soil Before Conversion (t C/acre)	***(A × B)*** ***Column C*** Total Annual Potential Soil Carbon Losses (t C/yr)	***Column D*** Fraction of Carbon Released over 25 Years	***(C × D) × 0.91*** ***Column E*** Carbon Released from Soil (MTCE/yr)
Tropical	Moist Forest	Primary					
		Secondary					
	Seasonal Forests	Primary					
		Secondary					
	Dry Forests	Primary					
		Degraded					
Temperate	Evergreen	Primary					
		Secondary					
	Deciduous	Primary					
		Secondary					
Boreal	Primary						
	Secondary						
Grassland							
Other							
						Subtotal:	

Worksheet 10.4-12: Forest and Grassland Conversion

Column A Emissions from Biomass Loss (t C/yr) (10-year average)	***Column B*** Long-Term Emissions from Soil (t C/yr) (25-year average)	***(A + B)*** ***Column C*** Total Annual Carbon Release (t C/yr)	***(C × 0.91)*** ***Column D*** Total Annual Carbon Release (MTCE/yr)

Worksheet 10.4-13: Abandoned Lands

Regrowth of Land Type		***Column A*** 20 Year Total Area Abandoned and Regrowing (acres)	***Column B*** Annual Rate of Aboveground Biomass Growth (t dm/acre/yr)	***(A × B)*** ***Column C*** Annual Aboveground Biomass Growth (t dm)	***Column D*** Carbon Fraction of Aboveground Biomass (t C/t dm)	***(C × D)*** ***Column E*** Annual Carbon Uptake in Aboveground Biomass, 20 (t C/yr)
Tropical Forests	Moist					
	Seasonal					
	Dry					
Temperate Forests	Evergreen					
	Deciduous					
Boreal Forests						
Grasslands						
Other						
					Subtotal:	

Worksheet 10.4-13: Abandoned Lands (Continued)

Regrowth of Land Type		***Column F*** Annual Uptake of Carbon in Soils (t C/acre/yr)	***(A × F)*** ***Column G*** Total Annual Carbon Uptake in Soils, 20 yrs (t C/yr)	***(Optional)*** ***Column H*** Total Area Abandoned, 20 – 100 yrs (acres)	***(Optional)*** ***Column I*** Annual Rate of Aboveground Biomass Growth (t dm/acre/yr)	***(Optional)*** ***(H × I)*** ***Column J*** Aboveground Biomass Growth (t dm/yr)	***(Optional)*** ***Column K*** Carbon Fraction of Aboveground Biomass (t C/t dm)	***Optional)*** ***(J × K)*** ***Column L*** Carbon Uptake in Aboveground Biomass (t C/yr)
Tropical Forests	Moist							
	Seasonal							
	Dry							
Temperate Forests	Evergreen							
	Deciduous							
Boreal Forests								
Grasslands								
Other								
		Subtotal:					**Subtotal:**	

Worksheet 10.4-13: Abandoned Lands (Continued)

Regrowth of Land Type		***(Optional)*** ***Column M*** Annual Rate of Carbon Uptake (t C/acre/yr)	***(Optional)*** ***(H × M)*** ***Column N*** Total Annual Carbon Uptake in Soils, 20 - 100 yrs (t C/yr)	***(E + G + L + N)*** ***Column O*** Total Carbon Uptake from Abandoned Lands (t C/yr)	***(O × 0.91)*** ***Column P*** Total Carbon Uptake (MTCE/yr)
Tropical Forests	Moist				
	Seasonal				
	Dry				
Temperate Forests	Evergreen				
	Deciduous				
Boreal Forests					
Grasslands					
Other					
		Subtotal:			

Worksheet 10.4-14: Total Carbon Emissions/Uptake from Forest Management and Land-Use Activities

(Column Q, Worksheet 10.4-9) ***Column A*** Net Carbon Emissions/Uptake from Changes in Forests and Woody Biomass Stocks (MTCE/yr)	***(Column D, Worksheet 10.4-12)*** ***Column B*** Net Carbon Emissions from Forest and Grassland Conversion (MTCE/yr)	***(Column P, Worksheet 10.4-13)*** ***Column C*** Net Carbon Emissions/Uptake from Abandoned Lands (MTCE/yr)	***(A + B + C)*** ***Column D*** Net Carbon Emissions/Uptake from All Forest Management and Land-Use Activities (MTCE/yr)

CARBON STORAGE TABLES FROM BIRDSEY (1992)

Table 1.1—*Ratio of total volume[1] to merchantable volume[2]*

	Above-ground ratio[3]		Below-ground proportion[4]		Ratio[5]	
Region	Softwood	Hardwood	Softwood	Hardwood	Softwood	Hardwood
Southeast	1.408	1.793	.163	.197	1.682	2.233
South Central	1.495	2.304	.163	.1971	1.7862	2.869
Northeast	1.820	1.808	.170	.155	2.193	2.140
Mid Atlantic	1.820	1.808	.170	.155	2.193	2.140
North Central	2.087	2.043	.170	.155	2.514	2.418
Central	2.159	2.240	.170	.155	2.601	2.651
Rocky Mountain	1.898	1.871	.158	.155	2.254	2.214
Pacific Coast	1.410	1.926	.158	.155	1.675	2.279

[1] Volume of all above- and below-ground tree biomass for all live and dead trees, including main stem, branches and twigs, foliage, bark, roots, and root bark.

[2] The gross volume of the central stem from a 1-foot stump to a minimum 4.0 inch top diameter outside bark, or to the point where the central stem breaks into limbs; less deductions for rot, roughness, or poor form; for live trees of commercial species at least 5.0 inches d.b.h., and meeting specified standards of quality.

[3] The ratio of total above-ground tree biomass to merchantable tree biomass from Cost and others (1990) and other Forest Service reports.

[4] The proportion of total above- and below-ground biomass below the ground (Koch 1989).

[5] The ratio of total volume to merchantable volume = data column 1 or 2 adjusted for the below-ground proportion (e.g., col. 5 = col. 1 ÷ [1 - col. 3].

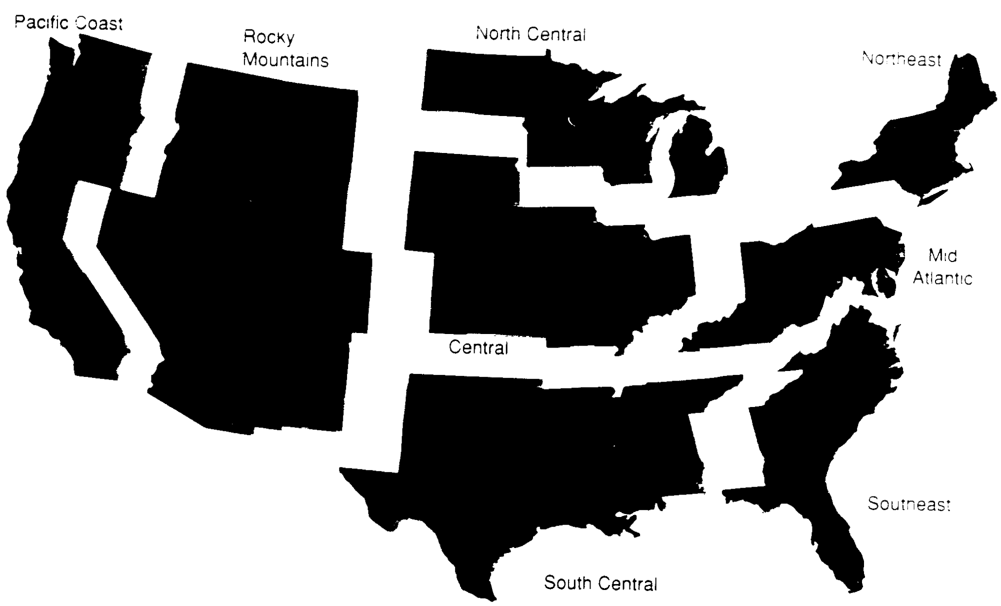

Figure 1—Broad geographical regions used to report estimated carbon storage.

Table 1.2—*Factors to convert tree volume (cubic feet) to carbon (pounds)*

		Specific gravity[1]		Percent carbon[2]		Factor[3]	
Region	Forest type	Softwood	Hardwood	Softwood	Hardwood	Softwood	Hardwood
Southeast and South Central	Pines	.510	.639	.531	.497	16.90	19.82
	Oak–hickory	.536	.639	.531	.479	17.76	19.82
	Oak–pine	.523	.639	.531	.497	17.33	19.82
	Bottomland hardwoods	.460	.580	.531	.497	15.24	17.99
Northeast and Mid-Atlantic	Pines	.378	.543	.521	.498	12.29	16.87
	Spruce–fir	.369	.525	.521	.498	12.00	16.31
	Oak–hickory	.374	.636	.521	.498	12.16	19.76
	Maple–beech–birch	.384	.600	.521	.498	12.48	18.65
	Bottomland hardwoods	.460	.580	.521	.498	14.96	17.99
North Central and Central	Pines	.421	.530	.521	.498	13.69	16.47
	Spruce–fir	.351	.480	.521	.498	11.41	14.92
	Oak–hickory	.416	.632	.521	.498	13.52	19.64
	Maple–beech	.372	.576	.521	.498	12.09	17.90
	Aspen–birch	.370	.465	.521	.498	12.03	14.45
	Bottomland hardwoods	.460	.580	.521	.498	14.96	17.99
Rocky Mountain and Pacific Coast	Douglas-fir	.473	.380	.512	.496	15.11	11.76
	Ponderosa pine	.416	.380	.512	.496	13.29	11.76
	Fir–spruce	.349	.380	.512	.496	9.80	10.67
	Hemlock–Sitka sp.	.434	.433	.512	.496	12.17	12.16
	Lodgepole pine	.423	.380	.512	.496	11.86	10.67
	Larch	.508	.433	.512	.496	14.26	12.16
	Redwoods	.416	.580	.512	.496	11.68	16.29
	Hardwoods	.424	.384	.512	.496	11.90	10.77

[1] Weighted average specific gravity of the three most common (in terms of volume) softwood or hardwood species within the forest type.

[2] From Koch (1989).

[3] Factor = specific gravity times the weight of a cubic foot of water (62.4 lbs) times percent carbon.

Table 1.3. *Estimates of organic soil carbon in relatively undisturbed secondary forests in the United States, by region*[1]

Region	Soil carbon (Kg/m²)	Soil carbon (Lbs/ac)
Southeast	7.74	69,044
South Central	7.58	67,626
Northeast	16.21	144,703
Mid-Atlantic	11.56	103,173
North Central	13.09	116,791
Central	8.33	74,302
Rocky Mountain	8.02	71,571
Pacific Coast	9.77	87,191

[1] Data from Post and others (1982).

Table 1.4—*Estimates of organic matter and carbon on the forest floor*[1] *by region and forest type*

Region	Forest type	Organic matter[2]	Carbon[3]
		(Kg/ha)	(Lbs/ac)
Southeast	Pines	20,026	10,361
	Oak–pine	15,132	7,829
	Oak–hickory	10,237	5,296
	Bottomland hardwood	11,480	5,939
South Central	Pine	20,026	10,361
	Oak–pine	16,375	8,472
	Oak–hickory	12,723	6,582
	Bottomland hardwood	11,480	5,939
Northeast and Mid-Atlantic	Pines	44,574	23,061
	Spruce–fir	44,693	23,122
	Hardwoods	32,207	16,663
North Central and Central	Pines	44,574	23,061
	Spruce–fir	44,693	23,122
	Oak–hickory and bottomland hardwoods	23,282	12,045
	Maple–beech and Aspen–birch	32,207	16,663
Rocky Mountain and Pacific Coast	Douglas - fir, Redwoods, Larch, Ponderosa pine	44,574	23,061
	Fir–spruce	88,520	45,797
	Lodgepole pine	25,922	13,411
	Hemlock–Sitka spruce	27,490	14,222
	Hardwoods	32,207	16,663

[1] All dead organic matter above the mineral soil horizons, including litter, humus, and other woody debris (excludes standing dead trees).

[2] Most entries from Vogt and others (1986), based on summaries of ecological studies grouped by broad forest ecosystem (e.g., warm temperate deciduous).

[3] Carbon (lbs/ac) = organic matter (kg/ha) x .58 (percent carbon) x .892.

Table 2.2—*Average storage of carbon in the United States by region, State, and forest ecosystem component, 1987*

		Forest ecosystem component			
Region and State	Total	Trees	Soil	Forest floor	Understory
	Lbs/ac				
Southeast:					
Florida	96,393	33,337	54,753	5,679	2,624
Georgia	120,371	47,399	64,637	5,710	2,624
North Carolina	140,870	57,049	75,939	5,258	2,624
South Carolina	124,576	51,719	64,627	5,606	2,624
Virginia	138,744	59,018	72,284	4,818	2,624
Total	124,146	49,515	66,577	5,430	2,624
South Central:					
Alabama	111,016	44,005	58,406	5,677	2,928
Arkansas	122,847	50,085	64,441	5,393	2,928
Louisiana	124,151	57,869	57,794	5,560	2,928
Mississippi	122,179	51,395	62,226	5,630	2,928
Oklahoma	88,818	25,318	55,888	4,684	2,928
Tennessee	134,491	57,694	69,089	4,785	2,924
Texas	101,783	43,474	50,047	5,515	2,747
Total	116,748	48,423	60,019	5,402	2,904
Northeast and Mid-Atlantic:					
Connecticut	178,993	59,118	103,769	14,699	1,406
Delaware	160,940	63,476	83,007	13,051	1,406
Kentucky	151,615	56,804	81,978	11,427	1,406
Maine	198,899	44,071	136,455	17,208	1,165
Maryland	164,791	71,066	79,769	12,551	1,406
Massachusetts	182,673	56,550	108,637	16,079	1,406
New Hampshire	190,440	59,937	112,586	16,544	1,373
New Jersey	137,830	40,235	82,229	13,961	1,406
New York	159,823	46,016	97,309	15,102	1,396
Ohio	149,357	49,391	87,888	10,671	1,406
Pennsylvania	147,234	47,947	86,950	10,931	1,406
Rhode Island	164,521	47,662	100,638	14,815	1,406
Vermont	188,276	57,316	113,995	15,594	1,371
West Virginia	150,212	56,356	81,524	10,926	1,406
Total	165,021	50,955	99,120	13,585	1,360

Table 2.2—*Average storage of carbon in the United States by region, State, and forest ecosystem component, 1987, continued*

	Forest ecosystem component				
Region and State	Total	Trees	Soil	Forest floor	Understory
	Lbs/ac				
North Central and Central:					
Ilinois	158,103	55,978	89,088	11,645	1,391
Indiana	168,576	59,215	95,870	12,100	1,391
Iowa	152,392	50,835	88,442	11,724	1,391
Kansas	123,201	39,007	71,571	11,232	1,391
Michigan	179,724	46,107	115,262	17,238	1,117
Minnesota	178,618	37,470	123,825	16,206	1,117
Missouri	122,662	40,639	68,238	12,394	1,391
Nebraska	139,336	40,933	84,102	12,911	1,391
North Dakota	161,225	33,563	113,466	13,070	1,117
South Dakota	149,313	40,839	87,809	19,273	1,391
Wisconsin	165,950	41,327	106,537	16,695	1,391
Total	162,948	43,446	102,957	15,279	1,266
Rocky Mountain:					
Arizona	106,218	44,658	49,227	11,256	1,077
Colorado	124,993	44,405	62,536	16,975	1,077
Idaho	148,190	60,961	64,417	21,735	1,077
Montana	185,368	67,902	95,732	20,657	1,077
Nevada	83,099	42,658	32,608	6,755	1,077
New Mexico	90,610	30,643	45,790	13,100	1,077
Utah	107,586	38,459	58,225	9,824	1,077
Wyoming	150,012	47,034	81,892	20,009	1,077
Total	128,040	48,316	62,941	15,706	1,077
Pacific Coast:					
Alaska	238,185	39,075	171,994	23,682	3,434
California	127,372	55,672	53,224	15,042	3,434
Hawaii	96,733	8,066	75,253	9,980	3,434
Oregon	172,749	64,469	82,976	21,870	3,434
Washington	202,655	83,073	93,911	22,237	3,434
Total	205,363	49,405	130,871	21,653	3,434
U.S. total	158,225	48,667	92,811	14,456	2,291

5

ALTERNATE METHODS FOR ESTIMATING EMISSIONS

No alternate methods have yet been approved by the Greenhouse Gas Committee of the Emission Inventory Improvement Program.

6

QUALITY ASSURANCE/QUALITY CONTROL

Quality assurance (QA) and quality control (QC) are essential elements in producing high quality emission estimates and should be included in all methods to estimate emissions. QA/QC of emissions estimates are accomplished through a set of procedures that ensure the quality and reliability of data collection and processing. These procedures include the use of appropriate emission estimation methods, reasonable assumptions, data reliability checks, and accuracy/logic checks of calculations. Volume VI of this series, *Quality Assurance Procedures*, describes methods and tools for performing these procedures.

Of the two methods described in Section 4 above—the stock approach and the flow approach—it is not known which method is more accurate. States usually have data that allow them to use one approach or the other, but not both. To our knowledge, no states have used both methods and thus, the results from the two methods cannot be compared for even a single state. The DARS scores provided later in this section are very close for the stock approach for trees and the flow approach for the entire forest (trees, understory, forest floor, and soil carbon)—indicating an equivalent level of reliability. As the explanations for the DARS scores show, the uncertainty comes from different sources. The stock method for understory, forest floor, and soil carbon has a lower DARS score, indicating greater uncertainty.

There are a number of areas where the basic method could be improved. Simplifying assumptions have been made in many places in order to produce methods that accommodate users with different levels of available data. The basic calculations focus only on the most important categories for emissions of CO_2, within a much larger set of forest management and land-use activities that impact greenhouse gas fluxes. Some activities are known to affect greenhouse gas fluxes, but cannot be quantified because of scientific uncertainty. Many of these issues are summarized below to assist state analysts in considering which, if any, of these possible refinements could be included in state inventories, either currently, or as scientific understanding improves in the future. Possible refinements or additions to basic categories could include:

Changes in Forests and Woody Biomass Stocks:

- *Prescribed Burning of Forests: Non-CO_2 Trace Gases*. Prescribed burning is a method of forest management by which forests are intentionally set on fire in order to reduce the accumulation of combustible plant debris and thereby prevent forest fires (which could possibly be even more destructive). Because carbon is allowed to re-accumulate on the land after burning, no net CO_2 emissions occur over time, although emissions of CH_4, CO, N_2O, and NO_x result from the biomass combustion. The proper method for estimating non-CO_2 emissions from prescribed burning will depend on the resolution of two issues: (1) the rate of change that humans have induced, and (2) releases of trace gases several years after the burning. Moreover, some scientists have suggested that prescribed forest burning may actually increase carbon stocks in forests. Unless these uncertainties can be resolved by state experts, it is suggested that activities associated with prescribed burning not be included in the method.

- *Soil Carbon*. In the basic calculations, no soil carbon accumulation is assumed while plantations are being established (or other tree planting activities are occurring) on previously non-forested lands. If plantations are established where natural or managed forests previously existed, then the carbon content of soils may not change significantly. However, it is possible that the establishment of plantations on previously non-forested lands could result in accumulation of soil carbon over time. Further investigation may be useful to determine whether this effect is significant enough to warrant its inclusion in the methodology. In addition, it is likely that different forest management practices can affect soil carbon over long periods of time, as in the case of agricultural activities.

- *Import and Export of Wood and Wood Products*. A significant portion of wood and wood products, including lumber, paper and paper products, furniture, etc., are shipped across state lines and internationally. This interstate and international trade in wood and wood products can potentially have a notable affect on current existing stocks of woody biomass in a state. This issue could be addressed in a manner similar to the import and export of energy and international bunker fuels, as discussed in Chapter 1. At this juncture, however, there is no recommended manner for attributing emissions related to the interstate and international transfer of woody biomass stocks. Also, developing a method for estimating these emissions is hindered by a lack of appropriate data. For example, the commercial timber industry has detailed statistics on activities associated with the export of wood or the production and sale wood products, but state-by-state consumption figures, especially for paper, paper products, and durable wood products, such as furniture, are not collected. This is an area that could benefit from further research and improved consumption statistics.

Forest and Grassland Conversion

- *Delayed Release of Non-CO_2 Trace Gases after Land Disturbance.* An experiment in a temperate northeastern forest in the U.S. found that clear-cutting resulted in enhanced N_2O flux to the atmosphere via dissolution of N_2O in the soil water, transport to surface waters, and degassing from solution (Bowden and Borman, 1986). Conversion of tropical forests to pasture has also been found to result in elevated N_2O emissions relative to intact forest soils (Luizao *et al.*, 1989). Also, the loss of forest area may result in increased net CH_4 emissions to the atmosphere, because soils are a natural sink of CH_4 (*i.e.*, soils absorb atmospheric methane). Various experiments indicate that conversion of forests to agricultural lands diminishes this absorptive capacity (Keller *et al.*, 1990; Scharffe *et al.*, 1990). With regard to grasslands, conversion of natural grasslands to cultivated lands in the semi-arid temperate zone has also been found to decrease CH_4 uptake by the soils (Mosier *et al.*, 1991). It is not clear what the effect on N_2O would be, unless nitrogen fertilization occurs. CO fluxes may be affected due to changes in soil temperature and moisture. These effects on trace gas fluxes, however, are highly speculative.

- *Fate of Roots in Cleared Forests*. The basic calculation ignores the fate of living belowground woody biomass (roots, etc.) after forest clearing. The carbon flux from belowground biomass could be analyzed in the same way as slash, perhaps with a longer decay time. Alternatively, it might be more appropriate to analyze belowground biomass by analogy to soil carbon calculations, as both are likely to involve long time horizons. This is an area for further development.

- *Aboveground Biomass After Conversion.* In the basic calculation, a single default value (22.4 tons dm/acre) is recommended for aboveground biomass which regrows after forests are cleared for conversion to crops or pastures. This may be somewhat variable depending on the types of crop or other vegetation which regrows. State experts carrying out more detailed assessments may wish to develop a state-specific estimate.

Abandoned Lands

- The basic calculations account for only the portion of abandoned lands which regrow toward a natural state. There may be additional releases of carbon from abandoned lands which continue to degrade. Where data are available, analysts conducting detailed calculations may wish to account for this phenomenon.

Other Lands

- Several other land-use activities affect the flux of CO_2 and other trace gases between the terrestrial biosphere and the atmosphere. For example, the changing areas and distribution of wetlands may be affecting the methane burden to the atmosphere. Freshwater wetlands are a natural source of CH_4, estimated to release 100 - 200 Tg CH_4 per year due to anaerobic decomposition of organic material in the wetland soils (Cicerone and Oremland, 1988). Destruction of freshwater wetlands, through drainage or filling, would result in a reduction of

CH_4 emissions, and an increase in CO_2 emissions due to increased oxidation of soil organic material. The magnitude of these effects is largely a function of soil temperature and the extent of drainage (*i.e.,* the moisture content of the soil). Also, since dryland soils are a sink of CH_4, drainage and drying of a wetland could eventually result in the wetland area changing from a source to a sink of CH_4. Loss of wetland area could also affect net N_2O and CO fluxes, although both the direction and magnitude of the effect are highly uncertain. Some possible methodological approaches for estimating emissions from freshwater wetlands can be found in the *Revised 1996 IPCC Guidelines for National Greenhouse Gases Inventories* (IPCC, 1997), if states are interested in estimating these emissions. However, there is currently no agreed-upon method for these source categories.

- Some experts have also indicated that changes in surface waters due to human activities can result in sequestration of carbon, and presumably other emissions or removals. An example is pollution of lakes due to runoff, which can cause eutrophication, increasing the carbon content of waters. Pollution of coastal waters could have similar effects. No data have been obtained thus far to indicate whether the carbon sequestration effects of such changes are significant enough to warrant inclusion in the method.

6.1 Data Attribute Ranking System (DARS) Scores

DARS is a system for evaluating the quality of data used in an emission inventory. To develop a DARS score, one must evaluate the reliability of eight components of the emissions estimate. Four of the components are related to the activity level (*e.g.,* the amount of forest area cleared), and the others are related to the emission factor (*e.g.,* the amount of biomass carbon content for a specific tree species). For both the activity level and the emission factor, the four attributes evaluated are the measurement method, source specificity, spatial congruity, and temporal congruity. Each component is scored on a scale of zero to one, where one represents a high level of reliability. To derive the DARS score for a given estimation method, the activity level score is multiplied by the emission factor score for each of the four attributes, and the resulting products are averaged. The highest possible DARS composite score is one. A complete discussion of DARS may be found in Chapter 4 of Volume VI, *Quality Assurance Procedures*.

The DARS scores provided below are based on the use of the emission factors provided in this chapter, and activity data from the US government sources referenced in the various steps of the methodology. If a state uses state data sources for activity data for one or more activities in this chapter, the state may wish to develop its own DARS scores for those activities, based on the use of state data.

Table 10.6-1 DARS Ranking of Stock Methodology for Estimating CO_2 Emissions from Forest Management and Land Use Change (Trees Only)

DARS Attribute Category	Emission Factor Attribute	Explanation	Activity Data Attribute	Explanation	Emission Score
Measurement	8	The default sequestration factor (for tons of carbon per ton of dry matter) is based on an average of species-specific measurements.	6	The US Forest Service makes direct, periodic measurements of forest timber stocks, using sampling. However, the Forest Service does not estimate stocks of non-forest trees (e.g., urban and suburban trees), and excludes some forested land areas due to restricted access.	0.48
Source Specificity	9	The default sequestration factor was developed specifically for forest management and land use change, but does not reflect differences among tree species. (If Birdsey's species-specific values were used, the score here would be ten.)	8	Activity data (change in forest stocks) are closely correlated with the carbon sequestration and emission process for trees.	0.72
Spatial Congruity	9	The default sequestration factor was developed for all states, and spatial variability is low.	10	The US Forest Service measurements of forest stocks are totaled by state.	0.90
Temporal Congruity	9	The default sequestration factor is based on an average of instantaneous measurements, not on measured sequestration over a particular time frame. However, the percentage of carbon in dry matter should not vary over time.	6	Annual change in forest stocks is estimated based on net change in forest stocks over several years. Year-to-year variability in forest harvests within a given state is expected to be moderate.	0.54
				Composite Score	**0.66**

Table 10.6-2 DARS Ranking of Stock Methodology for Estimating CO_2 Emissions from Forest Management and Land Use Change (Understory, Forest Floor, and Soil Carbon)

DARS Attribute Category	Emission Factor Attribute	Explanation	Activity Data Attribute	Explanation	Emission Score
Measurement	3	The default sequestration factors (pounds of carbon stored, per forested acre, in the understory, forest floor, and soils) are derived from a model, and are based on forest timber production and forest area for 1987; the assumptions made in the model are not public.	7	The US Forest Service makes direct, periodic measurements of forest area.	0.21
Source Specificity	10	The default sequestration factors were developed specifically for forest management and land use change.	4	Activity data (change in forest acreage) are somewhat correlated with the carbon sequestration and emission process for the understory and forest floor, but not for soil carbon.	0.40
Spatial Congruity	10	Separate default sequestration factors were developed for each state.	10	The US Forest Service measurements of forest acreage are totaled by state.	1.00
Temporal Congruity	7	The default sequestration factors are based on a model that uses 1987 data. Temporal variability is expected to be low to moderate.	8	Annual change in forest acreage is estimated based on net change in forest acreage over several years, but temporal variability is expected to be low.	0.56
				Composite Score	**0.54**

Table 10.6-3 DARS Ranking of Flow Methodology for Estimating CO_2 Emissions from Forest Management and Land Use Change

DARS Attribute Category	Emission Factor Attribute	Explanation	Activity Data Attribute	Explanation	Emission Score
Measurement	7	The default sequestration factor (for tons of carbon per ton of dry matter) is based on an average of species-specific measurements. However, it is often necessary to estimate the tonnage of dry matter per ton of commercially harvested dry matter.	6	The activity level equals growth minus harvests. Growth is measured as the product of the area and the growth rate. The area is measured by the U.S. Forest service about every five to ten years. The growth rate is modeled, based on the time required for a forest to reach maturity. Harvests are based on commercial harvest statistics.	0.42
Source Specificity	9	The default sequestration factor was developed specifically for forest management and land use change, but does not reflect differences among tree species. (If the Birdsey species-specific values were used, the score here would be 10.)	8	Activity data (forest growth and harvests) are closely correlated with the carbon sequestration and emission process for trees, understory, forest floor, and soil carbon.	0.72
Spatial Congruity	9	The default sequestration factor was developed for all states, and spatial variability is low.	9	Growth rates are modeled based on forest type, age, and latitude (Table 10.4-2), or based on forest type and species (Table 10.4-3); within each category, spatial variability is low. The U.S. Forest Service measurements of forest area are totaled by state. Harvest statistics are compiled by state.	0.81
Temporal Congruity	9	The default sequestration factor is based on an average of instantaneous measurements, not on measured sequestration over a particular time frame. However, the percentage of carbon in dry matter should not vary over time.	8	Growth rates are modeled over decades, but temporal variability is expected to be low (in part due to averaging out over different forest parcels of different ages). The U.S. Forest Service measurements are made about every five to ten years.	0.72
				Composite Score	**0.67**

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